

TOWARDS THE HUMAN-CENTERED DESIGN OF EVERYDAY ROBOTS

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in Human-Centered Computing in the
College of Computing

Georgia Institute of Technology
May 2011

TOWARDS THE HUMAN-CENTERED DESIGN OF EVERYDAY ROBOTS

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*To my beloved family,
from whom I have received endless support.*

PREFACE

This is a story about robots. It begins with robots that are designed for the homes to assist with daily chores like cleaning. It continues with stories of how these mechanical beings become companions, pets and loved ones over a long-term period, a unique phenomenon we have little experienced with other technical artifacts. It ends with reflections targeted for robot designers about how we should go about designing future domestic robots. Ultimately, this is the story about how we live and will live with robots in the home. And it is not sci-fi fiction.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisors, Rebecca E. Grinter and Henrik I. Christensen whose endless trust and support have guided me to see the light at the end of the tunnel. And I also thank my kind committee members for their priceless care and advice. I extend my gratitude to my colleagues, Heerin, Hwajung, Lan and Matt without whose assistance I would have never come this far.

Let me please thank my friends who have given me emotional support to never give up on this long path: my lab mates (Marshini, Andrea, Susan and Deana), and my AT&T colleagues (Linda, E-Lee, Madhur), and my GT friends (Jungju, Heeyoung, TJ, Younah).

Last but not the least, I thank all parties who supported my research - iRobot for having donated the robots, KORUS project for having funded to complete this thesis, all of my study participants who have endured my continued visits to their homes, and my baby robots.

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SUMMARY

The recent and rapid advancement of robotic technology brings robots closer to assisting us in our everyday spaces, providing support for healthcare, cleaning, entertaining and other tasks. In this dissertation, I refer to these robots as everyday robots. Scholars argue that the key to successful human acceptance lies in the design of robots that have the ability to blend into everyday activities. A challenge remains; robots are an autonomous technology that triggers multi-faceted interactions: physical, intellectual, social and emotional, making their presence visible and perhaps even obtrusive. These challenges need more than just technological advances to be resolved; more human-centered approaches are also required in the design. However to date, little is known about how to support that human-centered design of everyday robots.

In this thesis, I address this gap by introducing an initial set of design guidelines for everyday robots. These guidelines focus on leading designers to consider the rich interaction experiences that robots may elicit in the home, and to reflect on them prior to and during the development of technical specifications. As a tool to accomplish this, the guidelines present a design framework called Domestic Robot Ecology (DRE) that visually depicts how robots shape relationships with physical space, householders and domestic activities. Concisely put, DRE is a design tool to account for the social and lived experiences with robots at home. Additionally, the guidelines provide more detailed design suggestions for how robots appear, interact and engage to best support the lived experiences with robots.

These guidelines are based on four empirical studies undertaken to identify how

people live with robots in the home. These studies comprise a wide range of methods including interviews, online surveys, six-month-long field observations and participatory design sessions to mine insights about what interaction attributes of everyday robots elicit positive or negative user responses.

In addition to establishing an initial set of guidelines, this thesis shows how they can be applied to a real-world robot design process. The guidelines were deployed in the development of one type of everyday robot: a senior-care robot called HomeMate. It shows that the guidelines become useful during the early development process by helping designers and robot engineers to focus on how social and emotional values of end-users influence the design of the technical functions required.

Overall, this thesis addresses a question how we can support the design of everyday robots so that they are more readily accepted by users. I respond to this question by proposing a set of design guidelines that account for social and lived experiences of robots in the home, which ultimately can improve the adoption and use of everyday robots.

CHAPTER I

INTRODUCTION AND MOTIVATION

The recent and rapid advancement of robotic technology brings robots closer to tasks and applications that can assist people in their homes cleaning, ironing, education, health-care provision and more (illustrated in Figure 1). The International Federation of Robotics (IFR) reports that 6 million robots are in use in homes in 2009, which will grow to 11 million of them by 2013, which is equivalent to five billion USD market [65]. Despite the promising vision for the future, not all robotic developments have received success; ninety percent of all domestic robots accounts for only one type of domestic robots: cleaning ones [66]. It begs the question for the current robot design and ways to increase general acceptance.

Designing to increase acceptance for domestic technologies has been studied at length (e.g., [78, 89, 91]). These studies equally voice that designing smart technologies for the home needs careful attention. Our domestic spaces comprise routines that are continuously changing in less than predictable manners and have variables in the environment (e.g., clutter and technically naive users), which altogether provides



Figure 1: Examples of consumer-domestic robots (from left to right): iRobiQ (home tutor and informant), Chapi (smart home control), Roomba (vacuuming) and Dressman(ironing)

difficulties for computational processing [25]. The unique characteristics of robotic products add additional challenges in the design process. Robots, by their nature, encourage social interaction on levels that may differ from social interaction we experience with other technologies [52]. Also, robots often elicit a strong sense of lifelikeness, particularly in the way it makes movements in the physical environment, which leads people to treat them as a living creature [95]. Overall these characteristics generate a very unique, socially and physically embedded context for interaction experience. That said, robot design needs a particular attention to becoming socially-situated to increase acceptance. While studies strongly support the idea that interaction with robots is complex and draws deep social and emotional responses [13, 67, 95], few researchers have directly explored how to reflect these characteristics in robot design. This thesis addresses such design challenge by presenting a set of guidelines that can promote social interactions between human and robots, which in turn we believe can increase adoption and acceptance of these technologies into our homes.

With this thesis, I undertake this agenda for a particular type of a social setting: home. Domestic environment offers an interesting yet challenging design space because it comprises various types of target users (e.g., children, adults, and elders), and a less defined set of activities and routines that may occur at various frequency (e.g., daily or yearly). Thus nature of a domestic space can provide opportunities for rich and dynamic interactions, and yet it makes the design incredibly challenging to make the robot to fit into the environment. As a growing number of robotic products begin to enter home as a pet, caretaker, cleaner and so forth, I contend that it is a timely subject to investigate the design guides for domestic robots, particularly in the way that it can elicit a long-term interaction.

Moving onward, I begin to unpack the guidelines by first describing what motivated to create these guidelines (Chapter 2). Then, I explain how I developed them

from a series of empirical studies (Chapter 3 and frame into a set of guidelines Chapter 4). I present the assessment of them in subsequent chapters (Chapter 5). Finally, I conclude by revisiting thesis contribution and discussing limitations and future work (Chapter 6).

1.1 Thesis Overview

I answered this issue in the following three steps. The first step was to gain background knowledge on the user experience on domestic robots. To achieve, I conducted three empirical studies on how robots interact with domestic environments including householders, physical setting and ongoing activities. Each study respectively focused on the unique interaction incurred by robotic products at home, the socio-cultural trends of the robot users and their usage, and finally the long-term usage patterns from the adoption to 6-month-usage. Based on these studies [86, 81, 82], I drew design factors that could motivate people to continuously interact with robots.

The second step aimed to frame the design information in a comprehensive manner for robot designers. I presented those factors in a robot-centered design framework called Domestic Robot Ecology (DRE). DRE is a model that articulates the dynamic relationship established between a robotic product and the surrounding environment, and highlights how the interactions with each element change over time. Also, it comprises a set of design recommendations that can elicit positive user response, and promote for longer and continued interaction. Overall, DRE becomes a tool to provide a frame of reference (a stock of background knowledge) to robot designers, and helps them generate design concepts and requirements during the early development phase.

In the third and final step, I evaluate DRE for its applicability and usefulness. I deploy DRE in the early development process of Home Mate, a senior-care robot for the home, and learn what information within DRE designers find useful and desirable. This process will help expand and complete the initial design guides of

DRE with practical knowledge acquired from designers. With a refined version of DRE, I assess how much of impact it may bring to the design development process. To achieve, I conduct design activities with designers and robot-related engineers, asking them to create a domestic robot (in a concept similar to Home Mate) with and without DRE.

Thus, I took three steps to learn how I can support robot designers to better create long-term user experience. With this thesis, I propose an empirically driven design framework, DRE as a tool to achieve it, and evaluate its applicability and usefulness through some initial assessments.

1.1.1 Thesis statement

Robots designed to assist everyday lives in the home—referred to as everyday robots—have experienced adoption hurdles in the consumer market. One plausible explanation is the design focus on technical advancement rather than to user-centric viewpoints. Despite the growing voice in increasingly employing human-centered approach in robot design, little is known about how to guide the process. This thesis makes the first step towards establishing design guidelines for everyday robots.

This thesis first begins with the statement that there is a need for guidelines designated for everyday robots. The novelty and complexity of the robot interaction challenge designers to apply existing knowledge in user-centered design principles. After identifying the need, the thesis continues to develop guidelines specifically focused on augmenting robots as social and emotional agents. The key for robot acceptance and rejection largely depends on its ability to act according to social accords. Lastly, this thesis assesses the initial proposal of the design guidelines by applying in a real-world everyday robot development process. It identifies means to appropriate and refine complex guidelines for designers who are new to this robot design domain. As one alternative, it frames the lengthy guidelines in Domestic Robot Ecology (DRE),

a conceptual framework that describes the holistic social interaction elicited between robots and surrounding contexts. The visual depiction of robots’ complex interactions helps designers digest and reconstruct the robot experience even when they have not directly experienced robotic products in their own home. In sum, this thesis proposes an initial set of guidelines emphasizing social and emotional interactions as a catalyst to increase user acceptance, designated to support the complex and novel process of designing everyday robots. Collectively, these statements can be organized around four claims:

- Claim 1. There is a need for guidelines uniquely designated for everyday robots to overcome design challenges incurred by novelty and complexity of the domain.
- Claim 2. The guidelines need to inform lived experiences with robots in the home—from adoption to prolonged use—for the designers who are unfamiliar to this occasion.
- Claim 3. The guidelines should offer synthesized lessons about the design attributes that can increase user acceptance of everyday robots. Also, they should be framed to convey these insights in an effective manner that robot designers with diverse backgrounds can easily comprehend.
- Claim 4. Ultimately, the guidelines should help approach the design to become less technology-oriented and more human-centered.

Essentially, this thesis proposes the following statement: *Design guidelines that account for social and lived experiences of robots in the home can improve the adoption and use of everyday robots.*

1.1.2 Research questions

These four claims are supported by the following research questions. RQ 1. *What is the current design process for everyday robots?*: This is the “why guidelines” question.

Answers to this question justify the gravity of the thesis topic that robot design needs support to accomplish human-centered design. The search of an answer entails sub-questions:

- RQ 1.1 What are unique challenges in designing robotic products?
- RQ 1.2 Are there existing guidelines to overcome the challenges?
- RQ 1.3 If so what are they? If not, what causes the lack of them?

RQ 2. *How do people live with robots in the home?*: This question aims to learn “what goes into the guidelines”. To accomplish user-friendly robot design, designers need to understand how people live with robots from adoption to an extended use.

- RQ 2.1 What motivates people to accept robots?
- RQ 2.2 How do people interact with robots over an extended period?
- RQ 2.3 What do they want for future domestic robots?

RQ 3. *What are the key factors that play a crucial role in accepting or rejecting robots?*: Answers for this question should be based on the accounts learned from RQ 2. RQ 3 is the pursuit of design attributes that crucially influenced the positive and negative user experiences.

- RQ 3.1 What leads to positive user experience?
- RQ 3.2 What leads to negative user experiences?

RQ 4 *How can these attributes be represented as guidelines?*: Translating the key lessons from RQ 3 into practical design language is an important question. In a time pressed consumer product development cycle, design guidelines should be presented more effectively than lengthy and wordy documents. RQ 5. *What impacts do the guidelines bring in the design of everyday robots?*: By asking this question, it assesses

RQ 1-RQ 4; were guidelines useful (RQ 1), were the contents helpful (RQ2, RQ3), was the presentation appropriate (RQ4)?

- RQ 5.1 Does the use of guidelines affect the design process; do designers consider more in human-centered perspectives?
- RQ 5.2 Do designers comprehend the content in the guidelines, and find them insightful?
- RQ 5.3 Do designers find the presentation of the guidelines effective and communicative in the given development cycle?

RQ 6. What are the areas of improvements to refine the current set of guidelines? This is an important question to seek because establishing design guidelines for robotic products is a broad topic that clearly needs follow-up in the future.

1.1.3 Study overview

This thesis builds up on six studies to learn the answers to the above questions. The first three studies were conducted to get build a frame of reference about lived experiences with robotic products by interviewing, observing and surveying people who currently use robots in their home. Because of the limited availability of robots in consumer markets, these studies rely heavily on one type of domestic robots: iRobot's Roomba, the vacuuming robot. To complement the limited study target, the fourth study using co-creation methods [74] was undertaken to identify user needs and desires for future domestic robots. While these four studies inform much about user experience with robotic products in the home, it was unclear how they should be translated to become useful in the real-world robot design process. To deepen the understanding, I have performed a participatory observation in a robot design company for a month who were creating a senior-care consumer robot. Based on this experience, I have established an initial set of design guidelines, and then assessed

their impact in the design process by holding mini-design workshops with roboticists and product designers that became the final and sixth study. These studies are listed briefly in a chronological order (*see Chapter 2 for full study descriptions*)

- Study 1: interviews with 30 Roomba early adopters to learn unique user experiences with robots in the home.
- Study 2: an online survey of 375 Roomba owners to learn socio-cultural trends.
- Study 3: a long-term field study involving 149 home visits to learn use patterns from adoption to extended use.
- Study 4: co-creation sessions with 48 individuals to identify design requirements for future domestic robots.
- Study 5: participatory observation of current robot design process for a month.
- Study 6: design workshops with 30 robot designers to assess design guidelines.

While these studies aim to answer the research questions, it often takes more than one study to gain insights for respective question. Taking the question about unique challenges in designing robotic products (RQ 1.1) as an example, it draws answers from two user studies— field observation of real-world robot design (study 5) and robot design workshops (study 6). Additionally, it was complemented with an extensive literature review due to the limited access to consumer robot development to provide more generalized viewpoints on the design challenges. Below (Table 1) is summarized lists of how these studies were used to answer research questions, and ultimately to support the thesis claims.

1.2 Guidelines Preview

In this section, I provide a brief introduction of the guidelines to help understand what I refer to as “guidelines”. The robot design guidelines suggest two parts (Figure 2); the

Table 1: Thesis Overview

Thesis claims	Research questions (RQ)	Studies
Claim 1: there is a need for guidelines uniquely designated for everyday robots.	1. What is the current design process for everyday robots? 1.1. unique challenges in robot design 1.2. other existing design guidelines 1.3. their effect (or the lack of) in design	Appears in Chapter 2. Published in [47].
Claim 2: the guidelines need to inform lived experiences with robots in the home—from adoption to prolonged use.	2. How do people live with robots in the home? 2.1 motivation for robot adoption 2.2 interaction patterns over time 2.3 design needs for future domestic robots	Appears in Chapter 3. Published in [86, 84, 81, 82, 83].
Claim 3: the guidelines should effectively inform design attributes that can increase user acceptance.	3. What are the key attributes that play critically in user acceptance? 3.1 positive experience 3.2 negative experiences 4. How can these attributes be represented as guidelines?	Appears in Chapter 4. Published in [85].
Claim 4: the guidelines should help design become less technology-oriented and more human-centered.	5. What impacts do the guidelines bring in the design of everyday robots? 5.1 affect on the robot design outcome 5.2 affect on the human-centered perspectives 6. What are the areas of improvements to refine the current set of guidelines?	Appears in Chapter 5.

first part helps frame the holistic experience and the second part leads to determine detailed design components, such as form factor.

Robot design for everyday spaces is a complex activity. Robots are tightly intertwined with surrounding environments, building social relationships with people,

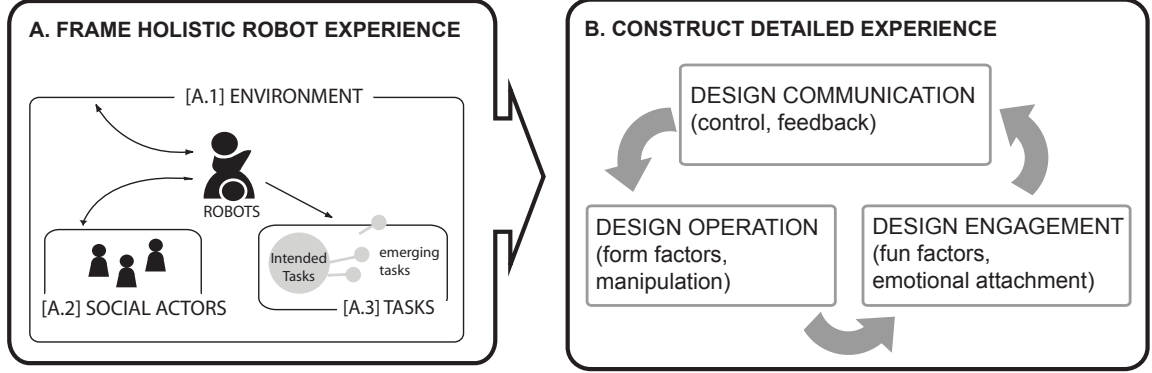


Figure 2: Design Guidelines Overview

and often set out to manage multiple tasks. Designers need to consider these multifaceted interaction experiences at an earlier ideation stage in order for the robots to not only become technical but also behave in socially acceptable ways. However, for many designers who are new to this process, it can feel burdensome. To better aid, the guidelines offer a visual representation referred to as “Domestic Robot Ecology (DRE)” that shows how a robot builds social relationships in the home (*simplified in the left side of Figure 2*). DRE works as a baseline, allowing designers to construct robot experience in a holistic manner as opposed to just focusing on the area of their expertise such as making the robot highly functional or aesthetically pleasing.

Once the high-level experiences are drawn, then the guideline suggests that designers should make more detailed design decisions, such as how the robot should look, behave and communicate (*in the right side of Figure 2*). Inspired by the existing consumer-robot design process, the guideline proposes to organize the extensive design agenda in three parts: interactions for robot operation (e.g., mechanical structure and form factor), interactions for robot communication (e.g., dialogues), and interactions for social and emotional engagements. These parts reflect the order of interactions related to low-level and mechanical operations, interactions related to controlling those operations, and finally interactions related to enriching the interactions. It is to allow designers to better structure the complex nature of the robot

interactions.

In the forthcoming chapters, I present what motivated to create these guidelines (Chapter 2), how I developed them (Chapter 3 and Chapter 4), and whether they actually made differences in the robot design process, and if so how (Chapter 5)).

1.3 Thesis Contribution

This thesis has two contributions.

First, I identified people’s lived experiences with robots over a long term. A growing volume of studies explore domestic robots and the user experiences they provide. However, few studies were conducted long enough to see temporal changes in interaction patterns, or had a large number of participants to present generalizable trends. In this thesis, I combined six-month-long observation with an online survey that had 379 participants; I learned not only how the user experiences change over time but also learned how robots become accepted and rejected during the course of time.

Second, I turned the empirical lessons into practical design guidelines. With this thesis, I synthesized and re-constructed the empirical lessons to become practical in real-world development. I created a design framework called Domestic Robot Ecology that designers and robot engineers can use as a tool to simulate user experiences with the robot being designed, helping the design become less technical and more human-centered.

CHAPTER II

RELATED WORK

I begin the search of robot design guidelines by learning what has been studied in related areas. Specifically, I wanted to gather an answer if the search of guidelines are necessary and if so why.

I present the related work in three steps. Firstly, I provide background information on everyday robots to explain what I mean by this term. Secondly, I describe how the interaction experiences with everyday robots is unique and different from existing computational artifacts (e.g., mobile phones), which confirms the reason why many of the existing design principles would not be applicable for robots. Thirdly, I offer an overview of what efforts exist to support the design of robots in domestic settings to identify how this thesis can contribute further to the current body of scholarly work.

2.1 Background: Everyday Robots

This thesis proposal aims to provide interaction design guidelines for consumer-domestic robots. To date, no agreed term exists for what defines and categorizes domestic service robots. However, several robotics institutes provide their own terminologies for broader types of robots. Robot Industry Association (www.robotics.org) defines a generic robot as “a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks”. Both International Federation of Robotics (IFR) and International Service Robot Association (ISRA) distinguish service robots from general robots by appending the description of “serving the well-being of humans” [65]. They describe service robots as “machines that sense, think, and act semi or fully autonomously to benefit or extend human capabilities, to increase

human productivity, and to perform services useful to the well being of humans” [3]. The taxonomy of service robots include Refueling, Agriculture and Forestry, Construction Industry, Renovating, Cleaning and Housekeeping, Guides & Office, Surveillance, Mining Applications, Firefighting, Search & Rescue, Sorting, Hotel and Cooking, Marketing, Edutainment, Hobbies and Recreation, Entertainment, Nursing Care, Medical Applications, Underwater, and Space [77]. As some of these service robots such as those for nursing care and edutainment carry strong social impact but little productivity centered goals (also known as Social Robots), Barneck and Forlizzi [3] call for the need to reinforce the definition to also reflect sociability. Their definition follows as, “an autonomous or semi-autonomous robot that interacts and communicates with by following the behavioral norms expected by the people with whom the robot is intended to interact”. The inclusion of sociability in service robots is crucial whether or not they carry strong social influence because they should perform tasks in an ecologically and socially acceptable manner according to [77]. Among these various types of service robots, this thesis focuses on domestic robots. IFR sets domestic robots into four categories of: domestic tasks such as cleaning and lawn mowing, entertainment and leisure, handicap assistance, and personal transportation. Synthesizing these definitions, I define domestic robots as: *“a semi or fully autonomous and intelligent agent that interacts and communicates with householders or other technical artifacts to perform one or more useful domestic activity”*.

For convenience, I refer to these consumer-domestic robots as *everyday robots* in this thesis, referring to those that perform household tasks to assist with our daily lives at home. Considering the large development focus on cleaning robots (over 90% of domestic service robots [66, 76]), I create the taxonomy of consumer-domestic service robots into two categories: cleaning robots and non-cleaning robots. These robots can again be divided into indoor and outdoor usage. Gathered from literature [77], the detailed taxonomy of domestic service robots follows as in Table 2.

Table 2: Taxonomy of Everyday Robots

Purpose	Cleaning Robots	Non-Cleaning Robots
Indoor Use	Floor vacuuming robots Sweeping robots Scrubber-dryer robots	Ironing robots Healthcare assistance Errand running
Outdoor Use	Gutter cleaning robots Garage cleaning robots	Lawn-mowing robots

2.2 *Unique Experience with Robots*

In this section I argue that robots elicit unique, emotionally-charged interaction experiences, and that this stems from the ways in which robots integrate into everyday settings. The discussion emerges from the simple observation that people naturally tend to treat robots similar to how they may treat living objects, and ascribe them with lifelike qualities, such as names, genders and personalities, even when the robot is not explicitly designed to elicit social responses [34, 86]. Here, I probe further how robots incur unique interactions with the discussion around how robots encourage social interaction, how they elicit a unique sense of agency, and how they demand attention to the greater, holistic, interaction context.

2.2.1 Strong social responses

Studies have shown that people tend to respond socially and to apply social rules to technical artifacts, such as a personal computer [63, 70]. Given that robots are one form of technology, it can be expected that this also happens when interacting with them. Yet, I contend that the way people apply social rules to robots, and the extent of this application, may differ from other computational technologies. Robots have physical manifestations, can exhibit physical movements and furthermore can autonomously interact within peoples’ personal spaces, properties that set them apart from other technological artifacts such as a PC or microwave [64]. Previous studies

in non-robot human-computer interaction cases show that peoples’ social tendencies toward technology can be deepened through socially-evocative technology designs [70]. Even for robots without explicit social designs, simple movements and abilities are often construed as lifelike (e.g., as with [34, 86]). Therefore, it is likely that robots, by their tangible nature including their ability to move autonomously and act in physical settings, strongly encourage people to interact more socially than other computing technologies [44].

2.2.2 Elicitation of active agency

People anthropomorphize robots —more so than other computing technologies. They give robots the qualities associated with living entities (e.g., [4, 32, 38, 81, 86]). I presume that this tendency to anthropomorphize is what encourages people to attribute intentionality to robots’ actions regardless of their actual capabilities. Intentionality helps give rise to a sense of agency in the robot; the word, agency refers to the capacity to act and carries the notion of intentionality [22]. While people have been reported to attribute agency to various other technologies (e.g., video game characters, movies [70]), I argue that the robot’s physically and socially-empowered interactions create a unique sense of active agency that robots can make autonomous and intelligent decisions. It makes the interaction experience with robots similar to playing with other social players in our everyday world, and hence ascribes lifelike qualities to robots. I posit that this active agency leads to developing affect-charged relationships; people establish strong emotional attachments to robots (e.g., [32, 36, 60, 86]) While people do sometimes exhibit emotional attachment to other (computational) artifacts, robots are unique in that they can actively return the emotional response and therefore deepen engagement in a reciprocal manner [52, 4]. Overall, research suggests that robots become active agents in people’s environments in a similar fashion to

living entities, such that these robots naturally integrate into social worlds and encourage emotional involvement in ways much less encountered with more-traditional technologies.

2.2.3 Holistic interaction experience

Interaction is embodied within our social and physical worlds [24, 88]. A person’s experience cannot be fully or properly understood by reductive accounts or limited perspectives [22], and includes difficult-to-quantify thoughts, feelings, personal and cultural values, social structures, and so forth [18, 24, 22]. From a person’s point of view, the meaning of experience cannot be separated from the wider, holistic context, and this has important implications for robot experience design. Robots’ unique active agency and life-like presence makes this wider context a particularly prominent part of the interaction experience. That is, the meaning of human-robot interaction often becomes more complex than simple screen-based input and output. The robot itself is a prominent and very active social and physical player within the everyday context, with its influence similar in many respects to a living entity. The human and robot mutually shape the experience similar to how two living agents may do. Consequently, the design of robotic products calls for an attention to holistic interactions by focusing on all surrounding contexts as variables that can influence the interactions.

In sum, social and emotional levels of interactions that play a critical role in a person’s acceptance of technological artifact, and scholarly research shows that this relationship is particularly prominent, unique and intertwined for interaction with robots [19, 64, 3, 13]. I present a more thorough comparison between robotic products and other computing technologies in [47]. Next, I discuss whether researchers have addressed these unique characteristics of robots into the design process, and if so how.

2.3 Existing Robot Design Efforts

To date, a number of studies exist to discuss design criteria for consumer robots (with or without a specific aim for domestic purpose) based on empirical studies (e.g., [34, 82]), or extensive literature reviews (e.g., [30, 25]).

2.3.1 Studies of everyday robots

As the development effort of everyday robots go back as long as 30 years ago (1970s) with particular interest in cleaning [69], a large volume of academic and industrial research exist on them. Literature [76, 77] shows that cleaning has become a major interest for two reasons: the task nature of cleaning is monotone and repetitive that makes it easier to mechanically replicate, and the cost of cleaning mainly (80%) comes from human labor that implies economic saving when replaced by a robot.

The earlier work on cleaning robots primarily discusses technical requirements such as, operation, navigation and safety (i.e., collision detection) [30, 76]. To explain more, operation and navigation requirements include, but are not limited to handling obstacles, path planning and execution, energy optimization, and time minimization [30]. Safety is another critical design factor to consider as the robot may run into pets, children and expensive artifacts. In addition to the requirements to the inner-working system, literature also briefly touch on the form factor design that it should be small to get to corners, light to carry around and low to get under furniture. The researchers commonly anticipate that the user interaction component will be the most challenging part in the design of domestic service robots as householders may vary in age and technical expertise [30, 76]]. In particular, Schofield calls for a special attention for Human Factors during the design process [76].

To respond, recently a growing body of research (e.g., [34, 32, 53, 55]) has shed lights on understanding how to design user interactions for domestic robots. Forlizzi

and DiSalvo’s seminal field evaluation of Roomba usage uncovered that this cleaning robot has influenced the housekeeping practices by increasing both opportunistic and planned cleaning. Also, they noted that physical environment played an important role in the use and assistance of the robot (i.e., removing obstacles). Further, they reported cognitive and emotional responses among householders triggered by the novelty of the robot, such as finding a lost earring by using Roomba [34]. Forlizzi describes how such bonds can create social dynamics among family members in her later work comparing Roomba with Hoover, a lightweight upright vacuum cleaner [32]. According to her, the use of robot has made cleaning a concern for all householders as opposed to just a single person. More importantly, she argues that it can be the basis for a long-term commitment by describing how Roomba was still used a year later, whereas the Hoover had been replaced by another vacuum cleaner. Kim et al. undertook a similar study, deploying five different vacuuming robots to homes in Korea in order to identify user trends that persisted across the robots [53]. From this empirical work, they identified that cleaning occurred in smaller units than an entire house, such as specific spots in the room from which they derived a design guideline for pathfinding. Despite these rich accounts of how people interacted with robots at home, still little is known about these interactions over a long period of time.

2.3.2 Studies of long-term human robot interaction

Studying interactions over a long-term is crucial because it deepens our insights about what truly occurs when a robot becomes a part of people’s everyday lives, and inform how to make products remain useful beyond initial adoption [34]. Indeed, the long-term Human-Robot Interaction has been actively studied in the areas of non-domestic spaces, such as such as offices [46, 67], schools [50, 87], and hospitals [60, 62]. They demonstrate that people exhibit different usage patterns as the robots pass behind the phase of adaption. For example, Kanda et al. [50] deployed a robot for nine

weeks in a classroom and observed elementary school children’s engagement. Robovie engaged in personally customized conversations with children. At first, children were excited and wanted to play with Robovie, but over time the frequency of playful interactions decreased. Nevertheless, Robovie’s continuous interaction made children see the robot as a part of the classroom, not a temporal toy. At eighth week of interaction, researchers found that the children decided to share their knowledge on Robovie by collaboratively making an information board about it so that they could better understand its characteristics. The studies with PARO (the baby seal robot) also showed long-term effects. Marti[60] identified that the use of PARO over three months brought changes in social behaviors (i.e., touching other people and expressing emotion) among children with mental disabilities. Also, children showed the manifestations of emotional bond, such as writing a letter to PARO’s parents to have them stay with the robot for longer period of time. However, the long-term interaction with robots does not always appear in positive directions. Other studies have documented the decline in people’s interest with robots over time. In their three month study, Tanaka et al.[87] tried robot (Qrio) dancing as a way to stimulate longer sustained interaction between children and the robot, but they saw the children’s interest decrease over time. Also, people began to ignore a large robotic guide in a hallway after just days of interaction [67], and even forgot about the robot on a mission in a three-month-long field trial [46].

These researchers not only offered empirical evidence of how long-term interactions occur between human and robots, but also provided design implications to make such relationship possible. Kanda et al. state that “long term interaction capability is a composition of various factors such as vision processing, speech recognition, number of capable physical tasks and plays, memory and so forth” [50]. Marti provides different perspectives that the long-term interaction can occur successfully when people view robots as social agents with affection instead of a mere objects [60]. Goakley et al.

note that environmental factors may also influence the long-term interactions, such as the number of people (group vs. individual) and the time of the day [39]. While these studies provide insights about what may contribute to successful long-term interaction, few have explored this agenda in domestic spaces.

2.3.3 Design agendas for everyday robots

Corresponding to the growth of empirical work on human-robot experiences at home, researchers studied at length how to support the design of everyday robots. Taken together this body of research identifies the following common design criteria a domestic service robot: form factor, intelligence, operation, sociability, interactivity, and environment (see Figure 3). Form factor includes shape (e.g., abstract, biomorphic or anthropomorphic), materials, and size [3, 25]. Researchers note that form factor plays an important role because it influences the expectations and attitude toward the robot [14, 23] and comfort level in interactions [71, 23]. Intelligence is the capability of sensing the context and determines appropriate behavior [3, 55]. It plays a pivotal role in robots’ ability to learn and adapt to the world [60, 49]. Operation refers to the robot’s movements [55]: simple motions, a composition of motions to perform a task, and the control of these movements (including autonomy versus operator driven [3, 25]). Researchers suggest that operation designs should reduce users’ cognitive load because the operators of domestic robots may not be technologically knowledgeable [25]. Sociability allows robots to behave following socially accepted norms. Social behaviors are important for increasing robot adoption because people tend to treat them as social agents [3, 32, 60]. Interactivity refers to the number of communication channels encompassing, vision, audition, touch, smell and taste [3]. These different modalities communicate and convey feedback, such as facial expressions and moods (e.g., [23]) and gestural behaviors (e.g., [93]). Both one-way (e.g., giving didactic information) and bi-way (e.g., playing games together) can occur [19].

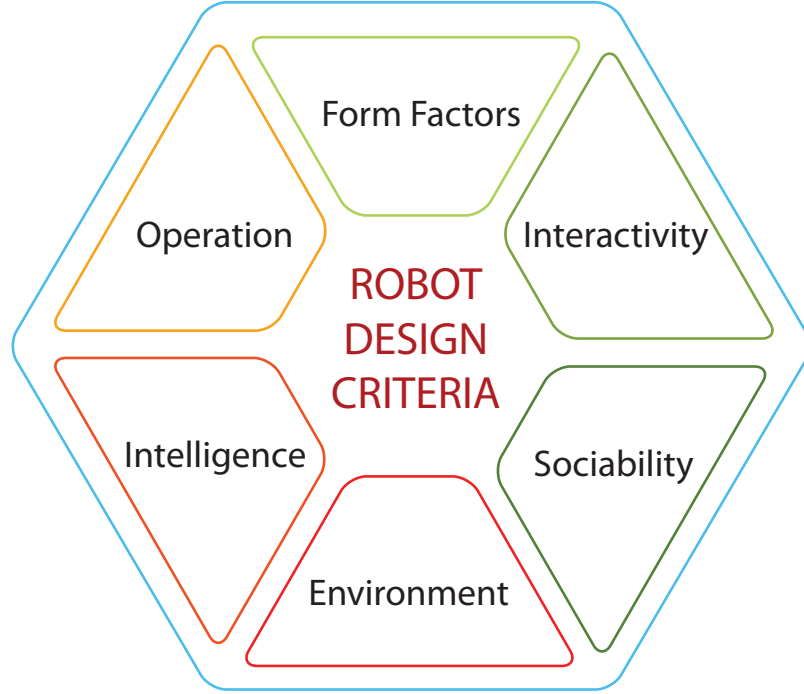


Figure 3: Six design criteria for social robots: form factor, intelligence, operation, sociability, interactivity, and environment

Finally, environment focuses on both the platform and potential obstacles (e.g., clutter) for robot design as shown in [25, 30]. Environment not only implies physical space but also other systems such as those focused on appliance maintenance and safety regulation [30].

However, these actionable items shed few implications to meet the specific design demands of real-world design process. They tell designers what to attend to by providing a list of important design considerations but do not necessarily reflect practical guidelines that can be quickly adapted by robot developers. In other words, these criteria inform designers what should be considered in the design, but do not explain how to design for it, or how those criteria interact with each other during the design process. Further, these guidelines, while partly based on lived experiences with robots, do not necessarily reflect the long-term experiences. I believe this thesis can

complement this gap by offering guidelines specifically tailored to real-world development process of everyday robots with strong emphasis on long-term interactions. I believe design guidelines that can encourage long-term interactions are particularly important to nurture the culture of living with robots and adopting more of them in the future. Moving onward, I describe our study procedure, and present the design insights.

They tell designers what to attend to, but not how to design for it, or how criteria interact with each other during the design process.

2.4 *Summary*

To summarize this section confirms the need for design guidelines specifically aimed for everyday robots. I explained the unique nature of interaction with robots; robots, by their very nature, encourage social interaction on levels that may differ from social interaction people experience with other technologies. Following from this, robots are (often accidentally) anthropomorphic and generate a strong sense of active agency similar to a living creature. Overall this generates a very unique, socially- and physically-embedded context for interaction experience. Building upon, I have presented a growing body of work that tries to set design criteria for everyday robots by either empirically observing how people live with robots or conducting an extensive literature review. Yet, the review of these design criteria illustrate the areas that this thesis can contribute to further. Below, I capture the summary of related work and how this thesis can add to the existing body of everyday robot design effort (Table 3).

The summary table shows two points that can be addressed further. Empirically, the current studies discuss little about long-term adoption and use that extend beyond two months. Also, the majority of the study method approaches to understand robot's lived experiences in qualitative means, having studied ten or fewer homes. It shows that empirical studies that explore long-term adoption and use over a larger same size

Table 3: The Summary of Related Work on Everyday Robot Design
Empirical Studies on Robot Experiences in Social Settings

Empirical Studies on Robot Experiences in Social Settings		
Related work	Current findings	Areas for more research
The work on home service robots [34, 32, 53, 55]. The work on home entertaining robots [36, 29].	Attachment formed to robots. Treatment as lifelike beings. Changed perception toward drudgeries (fun activities). New social activities around robot adoption.	Do these phenomena exist over time? Do these findings speak for a larger population (e.g., more than 10 households)?
The work on social service robots [50, 60, 46].	Long-term patterns exist in robot adoption and use in social settings. Excitement fades away over time. But robots are accepted as a natural part of the setting	The studies took place in public settings (e.g., school, hospital, office). Do these phenomena also apply to the home use?
Design-focused Studies on Everyday Robots		
Related work	Current findings	Areas for more research
The work on social robot design [3, 25, 23, 71, 19, 30].	High-level robot design criteria: form factor, intelligence, operation, sociability, interactivity, and environment (Figure 3).	Are they practical enough for a real-world robot development?

are necessary. Design-wise, the lessons learned from the current body of related work (the design criteria in Figure 3) have not been confirmed in a real-world robot design practice. That said with this thesis, I focus the design guidelines to provide two things: information on long-term robot experiences in the home that were generated from a larger number of participants than a single digit, and practical recommendations that can be applied in real-world development. The following chapter unpacks how I learn lived accounts of everyday robots over a long-term, and how I apply these lessons in real-world design settings to confirm the practicality.

CHAPTER III

LIVED EXPERIENCES WITH ROBOTS

This section describes the lived accounts of human-robot experiences in the home based on four studies. The studies include,

- Study 1: interviews with 30 Roomba early adopters [86].
- Study 2: an online survey of 375 Roomba owners [81].
- Study 3: a long-term observation of how 30 households adopt and use robots in the home [82, 85, 84].
- Study 4: co-creation sessions with 66 individuals to identify needs for future domestic robots [83].

I conducted four studies to learn the breadth and depth of the lived experiences. I first began by *interviewing Roomba enthusiasts* to understand if and if so, what unique experiences robots might possess. The results implicate that robots exhibit stronger social and emotional interactions with householders [86]. However, these results come from a very particular type of users. Therefore, I have undertaken an online survey with a larger number and a broader type of Roomba users to seek general socio-demographic trends to better understand who uses robots and how they manage the interaction. Further, this survey revealed the accounts of 114 people who did not like the robot and decided to stop using it. While these two studies offer interesting data of how people live with robots, they are largely based on self-reports and fall short of clearly depicting the long-term use from adoption to retention. It led to the long-term field study of how 30 households used Roombas over a six-month period in their homes. The first three studies provided abundant amount of stories

to deepen the study understanding of what it is like to have robots in the home. However, most of the reported user experiences is based on one particular type of robots: Roomba —iRobot’s vacuuming robot because of the limited availability of the commercial-domestic robots. I chose to study Roombas because they were the first robots distributed in the mass market, and hence became most familiar with people and made it easier to recruit. For the final study, I made an attempt to get beyond the accounts with Roomba by asking people to visually depict what they desire and expect for the future domestic robots, which allowed me to learn broader needs in robot tasks and design [83].

One advantage of conducting these studies is to solidify the methodological soundness for gathering robot experiences in the home by utilizing both qualitative and quantitative means. Semi-structured interviews were the central piece of user studies. And I complemented this process with hands-on activities including checklists, numeric ratings and generative activities (inspired by [74]). The data analysis consequently employed both qualitative and quantitative tools (e.g., t-test, ANOVA, Multiple regression analysis).

Here, I present the results with each study separately but only present those that led to design guidelines. And in Section 3.5, I synthesize the results across studies, and discuss a) long-term adoption and use of robotic products and b) design attributes that help and hinder such lengthy interactions. Following, I explain the methods of these four studies in depth, and present how they collectively spoke about long-term interaction patterns and design attributes for robot acceptance and rejection. These results became the basis for the initial set of design guidelines, which I present in the next chapter (Chapter 4).

3.1 Study 1. Interviews

3.1.1 Methods and analysis

In this study, I conducted interviews with 30 people in the United States, United Kingdom, Finland, and Austria. In each interview, I focused on three main themes. First, I asked about Roomba demographics: model types, number owned, and where and how often each robot was used. Second, I asked people whether, and if so, what they named their Roomba, whether they ascribed gender and a personality to it. Third, I asked participants to describe the advantages and disadvantages of owning and using Roomba and their opinions on potential improvements.

Among the 30 participants, all owned at least one Roomba: 18 owned just one, nine owned two, and the remaining three owned three, five, and nine (with two more being shipped) respectively. The average length of ownership among the study participants was 10 months, varying from one week to five years. The sample was fairly gender balanced with 16 men and 14 women who ranged in age from 27 to 76 years. Eight of the study participants were single. The remaining 22 participants came from households where they lived with a spouse or a partner. Among them, 10 families had children. The participants had a wide range of technical expertise based on the self-reports of their education, professional backgrounds, and their experience with technologies (I asked about latter to see if any of the participants were self-taught technology enthusiasts).

I transcribed and analyzed the interviews based on a thematic induction largely inspired by [79] and other related literature [36]. The analysis of the interviews relied on the phone interviews, because the email replies did not contain as much overall detail. However, the emails did provide supplementary data when counting frequencies (e.g. how many people named their Roomba). Hence, the quotes and observations described in this paper mainly come from the phone interviews.

3.1.2 Results

The study results showed that the nature of the intimate relationships people formed with their Roombas manifested in the next four ways: attitude change toward vacuuming as a fun activity, ascription of life-like attributes, active promotion, and environment modification. First, people spoke of happiness with Roomba because it positively changed their attitude toward cleaning from drudgery to a fun activity. As the use was considered fun, the work required to use Roomba, such as monitoring and rescuing the robot, and clearing off the floor. Second, people engaged their Roomba by ascribing it life-like and social characteristics. Many saw their Roombas as somehow cognitive and physical as well as having a personality, name and gender. This in turn helped them engage sufficiently so that they could talk and write about it, through which I argue, they formed a relationship with their robots. Third, people valued their Roombas and consequently took pleasure in demonstrating it to others. Study participants demonstrated how valuable they felt Roomba was by telling us how they recommended it to other people. Also, they have extolled the virtues of the Roomba to close friends and their extended family. Fourth, the strength of the relationship that the study participants felt with their Roombas also motivated them to modify their living environment to accommodate the floor vacuum, known more widely as "Roombarization". In a few cases, Roombarization brought drastic changes to the home, such as throwing away rugs, replacing refrigerators to run Roomba underneath, and cutting hair short to prevent from getting caught in the brushes.

This study supports that emotional qualities are important attributes that largely impacts the overall experience. In particular, the study results indicate that intimacy increases the potential of adopting robotic products, and helps users overcome reliability issues by attending to technical difficulties with sincerity.

3.2 Study 2. Online Survey

3.2.1 Methods and analysis

Researchers argue that surveys are an effective medium to collect data from a large sample size, to confirm trends in existing resources (i.e., demographic information), and to set expectations (i.e., generating hypotheses for laboratory experiments, and questions for semi-structured interviewing) before conducting costly detailed studies [35]. Finally, Bernard [8] notes that surveys offer an advantage when asking sensitive questions that people might not wish to discuss in face to face setting such as those about socially undesirable behaviors. I conducted an online survey because of the logistics associated with trying to reach a broad demographic sample (region, age). However, I am aware of the sample bias associated with Internet use-leaning towards the younger and more affluent. To recruit, I posted a message on Craig's List (craigslist.org) which was responsible for over 90% of the study data. To correctly assess the data bias influenced by the participants of Craig's List, I wrote to Craig of Craig's List to share the demographic data of the site. A demographic analysis of Craig's List users provided by Quantcast suggests that affluent men use it most, but also find that the site is in the 250 most accessed across the Internet with more than 5.4 million users monthly. I also posted the message to the Roomba review forum (roombareview.com) and distributed it through various mailing lists at the study institution. To my great surprise, the survey collected over 400 answers in just under seven hours (I did offer a \$5 Starbucks gift card to participants who completed it and are residing in the United States). After filtering out duplicated IP and mailing address and undecipherable answers (i.e., "asbsdg"), I ended up with 379 valid data sets.

The survey collected responses from 379 people (see the results in [81]). The survey had 265 current owners or users, and 114 participants who reported that they no longer own or use the robot. Depending on the answers given, a participant received

a minimum of 21 questions up to the maximum of 35 questions. The survey consisted of four sections focused on ownership (i.e., Roomba model owned, length of ownership and motivation for purchase), usage patterns in cleaning (i.e., frequency of use, extra manual cleaning), usage patterns not associated with vacuuming (i.e., naming, ascribing personality) and demographic information (i.e., age, gender, household membership, technical knowledge).

3.2.2 Results

The survey results reveal socio-cultural trends of who adopts robots and why they do it. Further, it begins to shed insights on those who show negative responses toward Roomba and decide to discontinue the use. In this section, I present four highlighting findings from the survey.

First, within the extent of the study survey data, I identified that Roomba users were younger (largely in their 20's) with high levels of education and technical knowledge. This description could suggest that they were technophiles and dominantly men, but I found many women owners were primary users too. Study participants also told us that many of them were not technophiles, or interested in science fiction, which leads us to speculate that they are not as enthusiastic as stereotypes about robotic ownership might suggest. Usage patterns among the study respondents seemed to be somewhat influenced by who they lived with (i.e., children and pets) rather who they were (i.e., their gender or interest in technology). Homes with children and pets reported much more engaged with robot, including having it play with children or chase their pets. I even identified that having pets seemed to be correlated with the tendency to ascribe personalities to robots although further work is needed to discover why that might be the case.

Second, I re-confirmed and expanded on the findings reported from other ethnographic studies of Roomba usage. Forlizzi and DiSalvo [34] identified that the use

of Roomba increased cleaning frequency. This survey mirrors this increase by presenting that more people cleaned on a daily basis after adopting Roomba. They also found that people valued Roomba for freeing them to perform other tasks [34], which I saw in the study data through the descriptions of what people did while Roomba is vacuuming, such as working in their office and putting children to bed. Like other studies [34, 32], I saw that people not only utilize the robot for its intended purpose of cleaning, but also they adopt it in other ways through naming it, playing with it, giving it a personality and gender (Table 4). However, this survey additionally reported that these activities do not appear uniformly across all users. Nevertheless, the study data begins to shed some light on how these non-cleaning activities help to build the bond between Roomba and their owners. They showed significantly higher satisfaction than those users who did not engage in such activities. This implies that researchers should consider a holistic user experience even when designing for a task-oriented because it can make a powerful and positive impact on the human-robot experience.

Table 4: Non-cleaning activities engaged with Roomba

Activity type	Number of responses (N=379)
Watch Roomba running for fun	276
Give a demonstration to others	217
Play and experiment	141
Ascribe a gender to Roomba	135
Name Roomba	87
Ascribe a personality to Roomba	44
Talk to Roomba (praise, greet)	42
Buy costume (dress up)	43
Hack the internal system	21

Third, the study suggests that the number of people who own a robot (and more) has grown rapidly in recent years, having purchased numerous types of domestic robots for vacuuming, mopping, entertaining and other household activities. About half of the study participants have owned at least one robot in the home in addition

to Roomba, which suggests that those who engender positive user experience with their first robot tend to employ more in the future (see Table 5). I support this argument by presenting how Roomba owners acquired additional robot. They either bought more units based on their first experience, or received it as a gift based on someone else’s positive experience. This implies how robots get introduced to the study home is critical (as also noted by [34]) in determining the future adoption of robotic products.

Table 5: Robots adopted to home

Types of Robots	number of robots
Scooba (mopping)	37
Robomower (lawn mowing)	47
Dirt Dog (garage cleaning)	27
AIBO (toy dog)	25
Dressman (ironing)	11
Paro (nursing)	13
Other robotic vacuum cleaners	3
Humanoid robot toys (i.e., Robosapien)	62

Fourth and finally, the study survey reports on 114 people (63 female and 49 male) who discontinued owning or using Roomba, which comprises 30% of the entire survey participants (N=379). I saw this to be the case more in dual-head households (N=89, 39 of them had children) than in single head ones (N=22). Considering that the domestic robot is relatively new in the consumer market and costs high (over 200 USD), I contend that this ratio is more than marginal, and needs be explored. Further, the study survey result shows that most of them (N=96) abandon the robot within the first year, which may be a short life span for a cleaning device—note that the average life span of major home appliances, such as the dishwasher is seven years (www.repair2000.com). Then, why do people discontinue the robot? The survey hints that the reason may be more than functional performance. As shown in Table 6, participants chose “unreliable operation (e.g., getting stuck on the rug tassel)” and

“loss of interest” as two primary reasons at the beginning.

Table 6: Causes for robot discontinuation

Reason for discontinuation	6 months or less ownership	7 to 12 months ownership	13 months and more ownership
unreliable operation	19	15	0
poor performance	27	10	3
dislikes from household members	0	16	0

However, for those who abandoned it after six months of usage, people reported social causes for dis-adoption, such as dislikes from householders —clearly raising a question what occurs during six-month-period in the social relationships between householders and robots. Further, one participant made an additional note stating that the lack of rich interaction led to the loss of interaction. She says: “ *if Roomba talked to me, I would probably have a more personal relation with the robot. It is noisy when doing work, but quiet when it comes to human interaction*”. Survey shows that the discontinued robots become forgotten. About half of the people (N=48) did nothing with the robot when lost enthusiasm; they just let it sit on the shelf or in the storage. Also, 17 people did not recall the whereabouts of the robot. It was striking because seven of them owned it for more than six months including one person who owned it for over three years before ceasing to use it. It seems that the robot when abandoned not only lost its practical value but itself became invisible from the householders’ cognition. One participant who made an additional note to this questionnaire says: “*While it was supposed to be vacuuming, it got stuck under our hamper in the closet-I didn’t know it was missing for months. Now it’s still there, but I know where it is*”.

Overall, the survey result identified their demographic and usage trends. The outcome of the survey suggests that Roomba users are equally likely to be men or women, and they tend to be younger with high levels of education and technical

backgrounds. Their adoption and use patterns illustrate the important role that gift exchange plays in adoption, and how the robot changes cleaning routines and creates non-cleaning activities. More generally, I argue that robot adoption is growing but the lack of social and emotional support in the design can critically affect the continued adoption as identified by 114 participants who decided not to use or own the robot anymore.

3.3 Study 3. Long-term Field Study

First two studies (interviews and an online survey) have hinted that robots bring unique technology experiences in the home in the way it elicits strong social and emotional relationships. The third study was an extensive effort to really understand how these social and emotional relationships develop over time by observing robot adoption and use in the wild.

3.3.1 Methods and analysis

I distributed 30 Roombas to 30 households in the Metro-Atlanta area in U.S. To learn long term effects, I studied them over six months. I visited each household five times to follow up on their experience. I had one household dropped out after fourth interview. In total, I conducted 149 home visits. I compensated the study participants by allowing them to keep the robot after study completion. During the five home visits, I used a variety of techniques to uncover the long-term experience. In between home visits, I encouraged the study participants to report on their experiences, such as via email. I separately published the study procedure in detail in [82]. Here, I briefly outline the methods I employed, and then describe participants and analysis.

I visited homes for the first time without Roomba. I wanted to document the overall domestic space including home layout and social dynamics among householders. To learn these points, I did semi-structured interviews with the head of the households (e.g., parents). In addition to interviewing, I asked them to take us on a home



Figure 4: An example of participant-created blueprint of P20’s home: yellow highlight for expected Roomba use and green highlight representing the actual area being used

tour, during which I focused on learning their cleaning routines including when, how often, and with what they cleaned. I used it as a baseline to compare the robot use against. I completed the first interview by asking them to draw a blueprint of their homes, and highlight the areas they expect to run the robot (Figure 4). I brought this blueprint in the recurring visits to compare with the actual use.

Approximately a week later, I brought a Roomba to their house, and captured the initial impressions. During this time, I employed two conditions across the households: different functionalities and different aesthetic configurations. First, I distributed robots with different functionalities (basic Red model, advanced Discovery model with self-docking ability, and the most advanced Scheduler model with scheduling feature). I distributed these three models to ten households each, balancing for demographical effects. I gave out different models to learn how functional configurations influenced users’ responses. Second, I deployed a personalization package



Figure 5: Personalization Toolkit and Customized Roomba

that contained stickers, and commercially available skins (Figure 5). I deployed it to half of the study participants to encourage them to personalize their robot. I wanted to learn whether, and if so how the personalization process can deepen the experience. Once they received the robot, I asked families to unpack and use it in my presence. Then, I conducted a debrief session. Participants rated their impression on a seven-point-Likert scale including, ease of use, usefulness, emotional attachment, entertainment, and degree of impact on the household. I repeated this rating on the recurring visits.

I returned two weeks later to find out what had changed since the arrival of Roomba. I conducted semi-structured interviews about their “Roomba routine” such as how often it was used, who used it, and how, when and where they cleaned. Additionally, I asked if they used the robots in non-cleaning activities, such as showing it to other people, and giving names and personalities. Then, I asked the study participants to do three activities to better assess their experience. First, I asked them to re-highlight the blueprint of their homes to show precisely where they had run and kept the robot. Second, I re-collected the experience rating. Third and finally, I asked participants to check off the activities that they had done with Roomba from a pre-generated list, such as hacking, naming, and demonstrating to others that I pulled

from the previous Roomba studies [86, 81, 32, 34]. Because these studies note that Roomba activities often occur collaboratively among multiple householders, I asked them to check together. Yet, I followed up individually to understand the detail, such as who led the activity and who participated. I repeated this activity checklist in the remaining interviews, and it became a good indicator whether or not Roomba usage changed over time.

I revisited the house two months later to learn if anything had changed since the study last visit. I kept the general interview format similar to compare how experience had changed over time. I conducted a semi-structured interviews about Roomba routines, during which I focused on how they used and maintained the robot because participants began to express difficulties about managing technical problems. Then, I asked the study participants to complete three activities: blueprint, experience rating, and activity list.

The fifth and final interview occurred approximately six months after they began using Roomba. To maintain consistency with the previous interviews, I began with the Roomba routine questions followed by blueprint, ratings and activity list techniques. Furthermore, in the study last interview, I focused on capturing Roomba routines in as much detail as possible, and therefore I incorporated two other generative activities that involved more than interviewing and observing. First, I wanted to understand who the primary Roomba users were and how they maintained the robot. They spoke of what they should have done instead of answering the study question. Next, I provided participants with a photo of Roomba with blank boxes that had a question asking on what occasions the robot generates sound, and a check list of Roomba activities focused on maintenance (i.e., have replaced battery). Both activities helped us calibrate their familiarity and determine whether or not they had used Roomba. After these activities, I asked participants to offer potential improvements that could make Roomba easier to incorporate into their households beyond these first

six months. I wrapped up the study by asking the participants what Roomba meant to them. Many discussed the robot with regards to whether it became a necessity or a luxury in their daily lives.

I used a snowball sampling method to recruit the 30 households, asking the participants for referrals to others who might show interest. In total, I had 48 participants (22 men and 26 women) from the 30 households. Below I summarize demographic information.

Household composition I balanced household compositions to mitigate effects on the overall usage experience [19]. I had 17 dual-head and 13 single-head households with 48 adults. Their age ranged from 18 to 67 years (mean = 42 years old). Half of the households (N=15) had 22 children who lived in the house. Their mean age was nine years, ranging from one month to 18 years. Also, 16 households had pets with three cats and 13 dogs.

Education and technical expertise Most of the participants had received college or higher education. I had 24 people with graduate degrees, and 20 people with college degrees. More than half the participants (N=19) self-reported as technical, meaning that they had an academic education, professional training, or hobbies in technology related fields. Despite the inclination toward high education and technical expertise, I had a large array of occupations. Examples include an aviation safety auditor, a physician, a lawyer, a head hunter, and a landscape designer.

House layout it varied among the study participants. Most common were multi-story houses (N=17), followed by single story (N=9), lofts (N=2) and apartments (N=2). House size ranged from 550 square feet (studio apartment) to 3,900 square feet (four bedroom, four bathroom house). Houses also varied in floors including hardwood, linoleum, tile, and carpet (and stained concrete in

lofts). Shared spaces such as living rooms and dining areas tended to have non-carpeted floors, while bedrooms and stairs tended to have carpet. Two houses had no carpeting due to severe allergies that family members had.

Cleaning Finally, given the study focus on cleaning, I also recruited families with cleaning services (n=7). Among the seven who hired cleaning services, six received the service every other week and one did it once a month.

I transcribed all interviews, and scanned and entered data from the user-generated materials, such as ratings, activity checklists, and blueprints. The analysis primarily focused on identifying how robots became adopted and accepted as a part of the household over time. Because I had a large volume of data (e.g., over a thousand pages of interview transcripts), I decided to turn to the existing literature related to technology adoption (e.g., [15, 28, 72, 78, 89, 91]), and used the findings as guidelines to code temporal experiences. Collectively, I gathered four temporal steps that householders experienced while accepting a robot in their house. The steps include:

1. *Pre-adoption*: During this process, people learn about the product and determine the value. Also, they form expectations and attitudes toward objects, which largely impacts the later user satisfaction [34].
2. *Adoption*: It refers to the first impression gained at the moment of purchase, or during the initial interaction [72].
3. *Adaptation*: During this period, people try to learn more about the artifacts by experimenting complexity in use and compatibility in the current environment, and make necessary changes to better incorporate [72]. Through this stage, people determine reaffirmation or rejection of further use [72].
4. *Use and retention*: It indicates the period when people begin to show a routine with a technology. Also, people show tendency to retain the use beyond the life

cycle of the current product by upgrading it or changing to the next generation model [45].

3.3.2 Results 01: Long-term accounts

The six-month-observation uncovered that long-term patterns exist in the use of domestic robots. In the households where Roomba was persistently and actively accepted, the long-term effects showed visibly through the status of cleanliness as in Figure 6. Here, I explain with empirical examples how such long-term patterns exist through four temporal stages of: pre-adoption, adoption, adaptation, and use/retention.

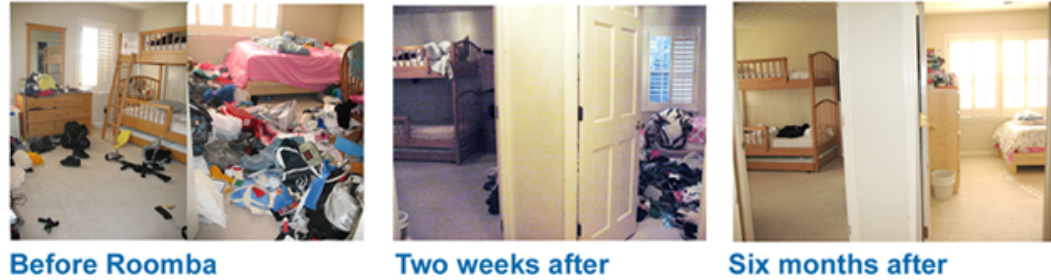


Figure 6: Long-term effect of robot usage in P15: the mother described that the robot use motivated her to undertake major cleaning throughout the house. Robots kept the floor clean and clutter-free, and she wanted to keep the rest of the house up to the same standard.

3.3.2.1 Pre-Adoption: Forming Expectation

Perhaps due to the little experience with robots, the study participants envisioned a rather simple relationship. People mostly described robots as a *tool* to improve the cleanliness of the home, and ultimately their current life style. They expected minimal human intervention in cleaning, and planned on increasing the vacuuming frequency from once a week on average to everyday. Moreover, they expected the robot to manage floor cleaning in the entire indoor areas. When I asked the study participants to draw the blueprint of their homes, and to highlight the areas they

P25 blueprint: before using Roomba



P25 blueprint: after six-month-use

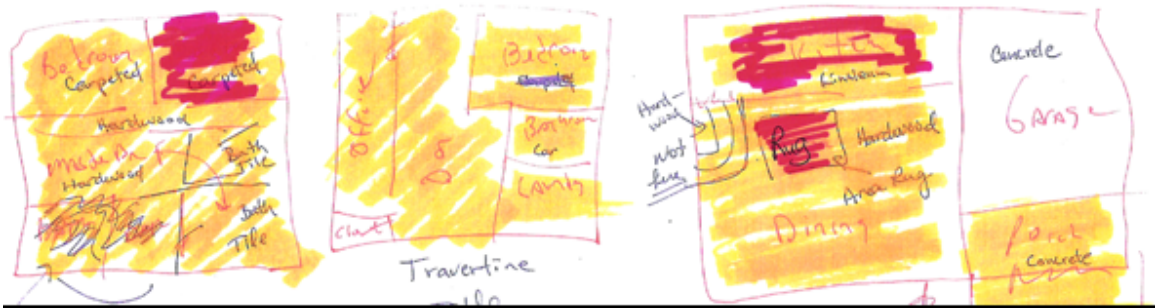


Figure 7: Above: P25 highlighted entire home as expected areas for Roomba use. Below: P25 localized cleaning areas as highlighted in red after six months.

would run Roomba, all of them marked the entire indoor areas. For example, P25 in Figure 7(above) highlighted all three floors to run Roomba except for the garage that they did not consider as a part of the indoor area.

While people expected the robot to bring visible impact in the cleanliness of the home, I learned that the user profiles, such as technical expertise and the need for cleaning assistance led them to anticipate different levels of impact by using a robot. The participants with high level technical knowledge, including one person who owned a robotics company knew the limitations of the current robotic products, and did not expect the cleaning quality to surpass manual vacuums. Six participants who were technically naive and had not known the existence of vacuuming robots prior to seeing the study recruitment relied much on the movies and science fiction, and hence expected advanced services, such as being able to detect dirt from a distance. Also, the household composition affected the expectation of Roomba as a practical

tool. For example, people who owned pets wanted the robot to decrease the amount of pet hair present in the house, and those who had physical disabilities expected a more independent way of living as they would not have to rely on others for floor cleaning.

Thus, people expected the robot to become a primary and an independent tool to manage the intended domestic task. And it led people to address two particular concerns, which I identified as impacting the satisfaction during the actual use. First, participants discussed how the robots would interact compatibly with the current environments, such as navigating in different floor types (e.g., tiles in the bathroom and unpolished wooden floors in the den), and operating through small objects (e.g., children’s toys). People expected robots to come prepared to handle these challenges. One male participant (P22) noted that he would rather not use a robot if he would have to put manual effort to help it navigate in the house, such as clearing up the wires off the floor. Indeed, during the actual use, he stopped running Roomba after a few trials because he had to pick up clutter before each operation. Second, the study householders emphasized durable and reliable robot performance, particularly because Roomba entered the domestic space to replace an existing cleaning tool that normally lasted for years. In fact, some of the study participants kept their floor vacuums over ten years. They added that the potential high-cost of robotic products made them to expect the reliable performance even more. In fact, one household (P9) gave up using it after five months due to the frequent technical failures despite reporting satisfaction in the cleaning quality that Roomba delivered.

3.3.2.2 Adoption: The First Impression

Participants responded more positively toward the robot experience after having used it for the first time. Participants showed higher satisfaction in all categories of user experiences that I asked them to rate after the initial experience (subsubsection 3.3.2.2).

Table 7: Comparing differences in the user ratings (1=least positive, 7=most positive) before and after the initial use of Roomba

	Before Adoption (mean score)	After Adoption (mean score)	Differences (T-test)
Intelligent operation	3.6/7	4.04/7	$t(47)=3.07$, $p < 0.005$
Useful in cleaning	4.93/7	5.19/7	$t(47)=1.60$, $p > 0.1$
Ease of use	5.13/7	5.35/7	$t(47)=1.24$, $p > 0.1$
Entertainment value	4.27/7	4.75/7	$t(47)=2.34$, $p < 0.05$
Emotional attachment	3.92/7	4.42/7	$t(47)=2.97$, $p < 0.005$
Overall Impression	4.58/7	5/7	$t(47)=2.11$, $p < 0.05$

During the initial operation, participants tried to assess the expectations and concerns they had prior to the adoption. For example, all households ran the robot for about 15 minutes, and confirmed the utility of Roomba as a cleaning tool by checking how much dirt and pet hair it picked up in the dust bin. In most of the households, Roomba showed better cleaning quality than expected, and hence received higher rating in ‘usefulness for cleaning’ category after adoption (subsubsection 3.3.2.2). Also, householders used the initial operation to assess robots’ compatibility with the environment. They followed the robot around the house, and began to make changes where necessary, such as by picking up the wires, and removing the area rugs. Further, they experimented the robots in the places they thought it would have difficulties with, such as near the staircase, and the door thresholds. Furthermore, they conducted experiments to protect their homes from potential Roomba hazards, particularly if they had pets and children. Parents put their feet under Roomba to see if it is accident proof. Also, all 16 households with pets made the robot run in the presence of their pets, and watched the reaction. In one household with chemically

treated concrete floors, the participant carefully observed if the Roomba brush made any scratches on the surface.

In addition to confirming Roomba as a useful tool, I saw a new type of relationship formed between householders and robots. This study revealed that householders began to view robots as *social agents* after the initial interaction. The data in subsection 3.3.2.2 support this finding. Participants rated non-cleaning related user experiences, such as intelligence, and emotional attachment significantly higher after the actual use. Empirical observations report similarly. During the initial interaction, people immediately ascribed lifelike qualities, such as Roomba’s intention to go to a certain place. The study participants noted that they felt Roomba’s movements led them to perceive lifelike qualities even though it did not resemble any living objects. They added that robots’ performance beyond their expectation, such as going under the couch, and returning to the charging base by itself increased the level of perceived intelligence because it did more than automating and replacing manual labor.

Perhaps owing to the richer social interactions, people felt the robot experience more entertaining. Boys in P20 (3-year-old and 6-year-old) chased the robot while yelling “It’s alive!”, and tried to jump over it. One teenage boy (P15, 13-year-old) recorded a video of Roomba operation on his cell phone to show to his friends at school. Children began to ask their parents if they could run it in their rooms. In both P25 and P29, I saw how parents used Roomba operation as a reward for completing the homework. Such excitement from children increased the positive experience to the parents. One mother in particular told us that she wanted Roomba to become an inspiration for the girls to clean up more often and pick clutter up off the floor.

3.3.2.3 Learn and Adaptation: Learning Affordances and Limitations

After the initial adoption, people continued to explore the robot to learn the technical limitations and affordances better, which I refer to as a stage of ‘Adaptation’. For

example, the study participants made exploratory operations, such as running in the porch and inside a van that had crumbs on the floor. As a result of their active exploration, they reported to running the robot more frequently than what they needed to keep the house clean. The study participants noted that this period normally lasted about a month after the adoption.

Robots constantly triggered changes in the physical environment as an active *agent*. They autonomously maneuvered around the home, and cleaned in the process. After a few weeks of usage, people noticed visual differences, such as seeing cleaner carpets and less pet hair, and feeling fewer crumbs while walking with bare feet. These changes in the environment assured the robot’s value as a useful tool, and motivated the continued use. However, as robots ran in the environment that had not yet been modified to accommodate them, they encountered several accidents, such as breaking a full-sized mirror, eating toys, and damaging furniture. Householders appeared more forgiving to the accidents during this period as they perceived it as a part of robots’ learning of the environment rather than as a result of their limited intelligence. Still, they did not want these accidents to occur again, and took actions to prevent them (Figure 8). Some of the actions included causal and temporary changes that they needed to repeat in each operation, such as folding area rugs, blocking Roomba navigation with everyday objects (e.g. toy cars), and picking up clutter. Other changes were more permanent; people placed a book under a lamp so that Roomba would not get stuck while trying to climb on it, and even cut off the rug tassel to prevent it from getting stuck on the fringe. Indeed, these accidents led robots to become a *mediating factor* for households to make changes in their homes.

In addition to the changes in the physical environments, robots elicited dynamic social interactions with households, pets, and visitors. First, the study participants continued to perceive the robot as a *social agent*, and began to apply social rules to



Figure 8: How people modified homes to incorporate robots

it. Most notably, 13 households gave names to Roomba within the first two weeks of usage; 19 households engaged in conversations with it, and referred to it in a gendered way using both male and female terms; and finally 3 households purchased costumes. Although these activities occurred throughout six months, I saw them most actively during the adaptation period. For example, I only saw six new names for Roomba after the first two weeks, and saw a decreased number of households ($N=12$) that reported to engage in conversations with the robot at sixth month.

Further, Roomba was a *mediator* influencing social interactions among householders. People used it as a conversation topic and a source for family entertainment. For example, P2 told that they intentionally initiated the self-docking sequence in their presence because it was fun to watch. In their words, *“it will normally find its base (after completing the cleaning sequence). But I still bring it out here in the kitchen (where the charging stations was placed) and push the button to make it go back because it is fun to watch. It goes back and corrects itself and goes back and corrects itself again it’s little bit incremental. That’s the study conversation piece. It’s my favorite part.”*

More notable social changes occurred in the households with teenage children who became primarily responsible for cleaning. Roomba attracted more householders to collaborate in the cleaning activities (as also observed in [33]). In some households, children took over the vacuuming responsibility. Children in P11 (boy, 11-year-old), P25 (boy, 10-year-old) and P29 (girls, 9-year-old and 12-year-old) became the primary

Roomba users. They not only ran the robot to clean, but also maintained it, such as emptying the bin and changing the filters. They self-taught this rather complex maintenance process by reading the manual, and in fact they knew the procedure better than their parents.

Additionally, Roomba *mediated social interactions* with people outside the households (friends and neighbors). For the first two weeks, the majority of the study participants have talked about it others (N=23 households), and demonstrated it to the household visitors and relatives (N=18 households). One household (P13) showed it to his friends in Guatemala via a Webcam. Two households (P8, P25) even brought the robot on their vacation, and ran it in the house they stayed to demonstrate the performance. In particular, P25 and the visiting families used Roomba as a source of entertainment, such as running it on the pool table, and watched it hit the ball for fun. Thus, the novelty factor brought by the robot stimulated people to learn and adapt the technology better into home. Consequently, it caused much change in the environments, dynamics among social members, and the relationship with the robot.

3.3.2.4 Use and Retention: Routine Practice and Maintenance

After adaptation, people found a routine for robot usage in their homes. It made people view the robot as a *tool* to perform intended tasks as they did so prior to adoption. However, the cleaning activity was no longer simple and repetitive as before. As an effort to adapt the robot due to the technical limitations (e.g., unable to map the house), householders carefully created strategies to use. One notable strategy was to localize the areas to run Roomba (i.e., running it in one room per operation), and to rotate the cleaning areas each time. That is, participants ran the robot more as a spot cleaning tool. For example, P25 ran Roomba only in the highly trafficked areas, such as the living room and the kitchen (highlighted in red in Figure 7:below), showing a contrast from how they expected to run it in the entire

house prior to adoption (Figure 7:above, in page 39).

The strategic use of Roomba included getting prepared for the robot to run, maintaining it, and storing while not used. By the sixth month, householders got into the habit of getting the house prepared for the robot to run; they quickly folded area rugs, and put away wires.

Also, participants created their own ways to maintain the robot, and incorporated it as a new domestic routine. The maintenance task had become an important part of the robot experience over time because it encountered several technical problems, such as failing to operate and dock. Because these errors often resulted from poor maintenance quality, householders intentionally placed a Roomba's cleaning tool (a plastic brush) next to their home keys, computing equipments, and kitchen appliances. This way, they would get easily reminded to take care of the robot. In the study, I saw that if householders still perceived the robot as social agents and responded emotionally toward it, they were likely to place more effort in the maintenance process (also reported in [86]).

Finally, householders developed strategies for storing Roomba. Functionally, the home base needed to sit near an electric outlet for charging. Yet, people felt negative to the idea of having a vacuum cleaner placed in an open space, and not in the closet. It led some of the participants to place Roomba in a less visible spot, such as behind a couch, and in an unused room. Then, another problem occurred; the robot became forgotten as it was out of sight.

Ultimately, the study participants sought places that were not obtrusive in the eye, but visible enough so they were reminded (Figure 9). For example, P25 put Roomba under the table right next to the main entrance, and described it as a perfect storage location. In their words: *"That place is perfect because it's not so obvious to the eyes but you can easily see it on the way out and get reminded to turn it on. And when you come back, the house is clean."*



Figure 9: Strategies for storing robots: subtly hidden to appear less obtrusive in the eye, but remained in a visible and highly trafficked area to get easily reminded of the use

3.3.3 Results 02: Positive and negative robot experiences

This study with 30 households that used robots over six months revealed a wide range of responses from those who described Roomba with companionship to those who returned the robot to us as they had “had enough”.

For the households with positive responses, I found overlapping results with the previous studies. Householders treated robots as a companion while ascribing personalities and names. The emotional bond often led to strong commitment to maintain the robot (also reported in the first study (Interviews)). Interestingly in this study, I even found one female participant (P8; single, 44 yrs) who carefully wiped Hazel (robot name) with water in the kitchen as if she bathed it. Further, she took out her upright vacuum and sucked the dust in the parts of Roomba where she could not reach with her hand. She went through the effort of vacuuming her vacuuming robot to be able to use Hazel for a long period of time. She described the extensive caretaking process as “putting a baby down and carefully removing the diaper and wiping the dirty areas”. I learned that such a strong emotional bond occurs stronger for the household that used the personalization toolkit distributed. Speaking of the personalization toolkit, six out of 15 households that received have customized Roomba. This explicit encouragement to personalize—when used—seems to help engage with robots. All six households who personalized Roomba reported that they felt more

connected to the robot, seeing it as “more like our Roomba instead of a Roomba”. This suggests that personalization helps Roomba users to feel increased attachment with the product, as the literature suggests [10, 11]. However, the participants also said that personalization deepened their acceptance of Roomba as a member of the household. For example: “(P24 Mom) when we didn’t put any decoration, it was just a robot. After decoration, it feels less mechanical. I feel closer to it. It feels like an entity”, “(p15) after decorating, it made me feel more committed using it. It just made it a part of our family. Not just a machine or a robot, but a part of family”. Further, such view of Roomba led some participants to think it performs better. “(P24 son) it feels like it can get more stuff done better cuz it’s closer to human now”. This emotional connection between humans and robots leads to positive user experience such as, promoting longer-term use by encouraging people to take the time and effort to maintain it (as also was identified in the first study (interviews)).

However, it struck us that these strong and positive responses became lost over time in many households. At the beginning of the study, I saw how teenage children from four households quickly took the responsibility of vacuuming as they enjoyed playing with the robots. At six months, none of the children retained the same degree of excitement, and they only used the robots when told to clean their rooms. Over all, only a third of the households (N=11) told us that they would definitely buy another Roomba after the current one broke. Six households reported that they would not buy one. Half of these households had completely abandoned the robot and had not run it for more than three months. The majority of the study participants (N=16) said that they might or might not consider buying another after first trying to live without it. These households appreciated the convenience of the robotic vacuum but thought it insufficient to replace their existing cleaning practices. Hence, they perceived Roomba more as a luxury item than as a necessity. The mapping practice they conducted at the sixth month (Figure 10) supports this response, during which



Figure 10: Concept map participants created to compare Roomba value with other home technologies.

they placed stickers of each household technologies (including Roomba) on the axes: ‘not necessary to necessary’ on x-path axis and ‘enjoyable to not enjoyable’ on y-path axis.

I measured the arbitrary distances of the sticker location-in the range of 1 and 22-where people marked for the necessity of Roomba and upright vacuums. I ran a T-Test to compare the difference in the perceived necessity, and the result did not show any significant differences ($t(60)=0.68$, $p=0.5$). Roomba seemed much more enjoyable than upright vacuums ($t(60)=5.4$, $p < 0.001$), which might explain why people used this robot longer in the Roomba-Hoover comparison study [32]. However, it struck us how Roomba did not seem any more enjoyable or more useful compared with other household technologies, such as TVs, espresso machines, cell phones and more. The average value for enjoyment and necessity of all 28 household technologies I offered was 14 respectively (1=minimum value and 22=maximum value). The mean value for Roomba’s enjoyment and necessity was 12 and 14 respectively. Of course, such numeric comparison may overly simplify the rich user experiences. Yet, the values

imply that the strong social and emotional responses displayed by other previous studies somehow failed to retain over time, and hence signifies the importance of exploring the attributes that drove users away from accepting robots in their homes.

To better understand the overall responses toward Roomba experiences, I asked the participants to rate on a seven Likert scale whether they would feel inclined to recommend it to others (7=strongly agree, 1=strongly disagree). This question was inspired by the second study (online survey) that marked social distribution as a manifestation of a positive response. On average, they rated it at five that referred to "somewhat willing to recommend it to others". Because less is studied about how robots fail to get adopted —positive experiences have rather been well studied by [34, 32, 86, 84], I focused on identifying challenges for robot acceptance. That said, I decided to closely study those that rated below average ($N=14$, mean score for willingness to recommend=3). In particular, I wanted to understand what factors contributed to the low scores, which led us to run multiple regression analysis (stepwise). I had the ratings for the "willingness to recommend" as the dependent variable while used other ratings on ease of use, usefulness, attachment, perceived intelligence, and entertainment as independent variables. The result returns with a plausible model (adjusted $R=.77$; $F(3,11)=16.36$, $p<.0001$) that pointed to three significant factors for negative user responses. In the order of significance, the three factors include: emotional attachment (mean=2.27, $Beta=.72$, $p<0.001$), perceived usefulness (mean=3.20, $Beta=.48$, $p<0.005$), and entertainment value (mean=3.07, $Beta=.30$, $p<0.05$). The other two values (ease of use and perceived intelligence) did not appear as significant factors. The data imply that the low level of emotional attachment, lack of perceived usefulness, and little entertainment value significantly influenced people not to recommend the robot to others. Further, it is notable that this statistical model shows that emotional attachment played a larger role in shaping negative impressions than perceived utility.

Overall, the long-term study drives four potential attributes that could lead the robot being difficult to get adopted. They include the lack of useful performance, loss of interest and entertainment value, breakdown of emotional bonds, and householder dislikes. In this section, I explain each attribute with empirical evidence from the study.

3.3.3.1 *Lack of useful performance*

First, I hypothesized that the advanced features would help people view this robot as more capable, and hence more useful—which was why I deployed three different types of Roombas. However, the results showed that little connection existed between having advanced functionalities and the overall user satisfaction. Table 8 shows that people did not significantly differ in their ratings of perceived usefulness between Red, the basic model and Scheduler, the most advanced model with automatic docking, more cleaning modes, and a timer ($t(152)=0.25$, $p<0.4$). Further, the Discovery model that had automatic docking and a remote control was rated significantly lower than the basic Red model in both the perceived usefulness ($t(153)=3.45$, $P<0.0004$) and overall impact on the household ($t(153)=3.72$, $P<0.0002$). I found similar results between Discovery and Scheduler model.

Table 8: Comparing Roomba Models

Roomba model	Perceived usefulness (7=most useful)	Impact on the Households (7=greatest impact)
Scheduler	5.16/7	4.72/7
Discovery	4.30/7	3.26/7
Red (basic)	5.11/7	4.17/7

I speculate that Discovery was rated much lower due to its frequent failure to dock. At first, householders seemed excited about it, and told us this capability made Roomba more intelligent than expected. Over time, they became disappointed at its low success rate to dock. In two households, the docking station itself failed to work

and at the last interview, they spoke animatedly about fixing the dock as a necessary future improvement. Scheduler also shared the same docking module. However, participants noted the timer function that initiated the robot without failure made it appear an intelligent and reliable technology. It means that even when the docking failed in these families, the reliable timer made up for the overall impression. Red models users did not complain about the fact that they had to manually place the robot to the charging station as they took it as the opportunity to clean it up. This suggests that functional capabilities do not equal usefulness, but perhaps reliable operation does. Further, it compensates for other functions that are prone to errors.

Second and lastly, householders no longer perceived the robots as useful when they gave piecemeal support to the intended task. In this study, only seven out of 30 households never went back to manual upright vacuums. Other 23 households used Roomba as complementary tool. This piecemeal support to the intended task in part came from the robot's insensitivity to the environment (e.g., poor navigation), and in part came from its little compatibility with other household routines. Roomba had limited capability to navigate around the house. It neither recognized the entire layout of the house, nor tracked where it had cleaned. Moreover, it ran on a random algorithm, and cleaned the places it had gone over several times, as well as missing spots. Consequently, householders felt that letting it run on its own decreased its efficiency, and thought that the right way to solve this problem was to localize its use. For example, P31 only ran Roomba in the kitchen and dining area where food crumbs were left by children and from meal preparation. It made people plan to use the robots, and created undesirable routines. It did not deliver the promise of autonomous cleaning at one push of a button. Indeed, two households (P18, P30) discontinued the use for several months until they decided to relocate the robots to their lake houses. The mother of P30 (married, 47 yrs) describes why she felt difficult to use the robot: "it is a little difficult to use because I am like a clutter bug so I kind of

have to plan to use it I had to move the rug, roll up (the big carpet) and had to push all the fringe underneath. It's not like you can just push the button and leave the house." The households with scheduling features preferred the convenience of automated start, and did not implement specific plans to complement the environmental insensitivity. It caused a serious damage to one household (P7; married, in 30's). P7 scheduled to run robots every day at six am in order to control the amount of dog hair in the house. Then, the robot was involved in an accident which caused them to cease all use and to refuse my offer to replace to a new one after two months: "During the night one of our dogs had an accident leaving a large pile of feces in the living room. When the Roomba began to vacuum that morning (6 AM) it spread the feces throughout the living room, hallway and office. We were able to steam clean the carpets, but we haven't been able to get all the feces out of the Roomba without using water..." In addition to the poor sensitivity to the environment, I learned that little compatibility with the home routines could diminish the perceived usefulness. Previous studies report how people liked how the robot saved time by allowing them to conduct multiple tasks [12]. But not all participants experienced the time-saving benefits particularly because Roomba created a large level of noise (from its motor). In particular, P20 (married, in 40's) had a custom-built house that had a hugely open living space with high ceilings, which is reportedly an ideal place for a robot to run (iRobot.com). However in this house, the room created loud echoes, and amplified the level of noise greater than other houses that I visited. Consequently, P20 used the robot less than five times during the six months study period. Householders envisioned a robot service while they could relax and watch TV, or supervise homework for their children. Because the noise prevented from such usage, the householders had to seek separate times to run the robot. Because the robot ran for an hour or more to complete a cleaning cycle, they found it challenging to even initiate the use. Compatibility with household values became another reason to minimize the use. One householder (P5; single mom,

41 yrs) prevented her children from using the robot. During weekday casual cleaning, she let her sons use the robots. However on their scheduled cleaning day (Saturday), she did not allow them to use the robot and insisted that they continue to use brooms. She felt cleaning was an important part of the home education that boys should learn. With Roomba, she noticed that her 9-year-old and 11-year-old boys began to take robotic assistance for granted in the home, and feared that they would never learn to clean.

3.3.3.2 Breakdowns of emotional bonding

The multiple regression analysis shows that the low ratings for attachment lead to negative user experiences. For robotics, emotional attachment has usually been considered as a bonding relationship that makes people view this technology as beyond machinery and more lifelike [12]. The qualitative analysis sheds insights that it is not simply the lack of bonding that causes the negative experience. Those who never considered Roomba more than a piece of machinery still showed positive relationships if it operated reliably. The negative impression seemed to occur at the breakdowns of the emotional bonding.

Previous studies show that people build up emotional bonds with robots when they feel robots offer life-changing experiences [12, 16]. In this study, I heard similar stories of how the robot increased the quality of their lives. Female participants who were divorced or otherwise alone at home said that robots' motions provided emotional comfort because the sounds reminded them of the presence of another and reduced their loneliness as if they had a "buddy". Similarly, the mother in P24 (married, 46 yrs) had used Roomba as an emotional alarm, such as having scheduled it to run daily at five in the morning. She told us that the diligent cleaning sound woke her up more pleasantly as she knew she would take her first step of the day on a clean floor. P4 (single, 30 yrs) added that her Trilobite (or 'Lobite as a nickname)'s sound

provided an extra sense of home security while she was away. She believed Roomba's vacuuming noise could prevent potential break-in attempts by making people think someone was at home. Indeed, her home got broken into, and she bought another Roomba to replace her stolen one.

However, I learn that these emotional bonds break when things go wrong. Taking P4 as an example, she frequently ran her Roomba while she was absent. She adjusted the home extensively; she spent about 10 minutes to re-arrange chairs, trash cans and wires per use. One day when she came back, the robot happened to drag the wires around, and tripped over a full size mirror. Feeling angry and disappointed, she made the robot suck the glass shards, which caused to tear up the rubber parts of the brush. However, she told us the robot got what he deserved. After that incident, she referred to his personality as stupid, and showed us how she reprimanded the robot by slapping his butt with her slipper when he made mistakes. One big disappointment changed this user's attitude from wanting to protect it from harm to losing the motivation to care.

The breakdown of emotional bonding made the mother of P9 (married, 56 yrs) stop using it after all. She had wrist injuries, and could not clean under furniture for more than seven years. When I brought Roomba, she expressed excitement of how it would help her maintain the house to the level she had dreamed of. Once she began using Roomba, she quickly realized how this robot additionally provided emotional comfort. She named her robot Ricky, and wrote us emails about how much she loved him. She actively promoted this robot to the house guests, and prided that she even made one person purchase it. However, P9 began to experience technical problems after two months. Roomba had a small object stuck on its front wheel and could not move, which she suspected that I intentionally contemplated to test her emotional frustration. She did not think that the robot could malfunction so easily. At fifth month, it stopped working and moved in a circle because accumulated dust

inside the robot clogged its sensors. Despite her technical naivety and intimidation toward complex systems such as robots, she tried her best to revive the robot. She thoroughly cleaned it several times, and fully charged the battery repeatedly. However, Ricky failed to communicate with her to overcome this challenge. Roomba had actually diagnosed the problem, but it expressed the error condition through beeping arbitrarily. She told us that she felt betrayed and lost the trust that she built with him over months. Finally, she abandoned using it. When asked if she would buy it again, she responded negatively because she felt that she could no longer rely on Ricky, which she added as an important criterion for a household appliance.

3.3.3.3 Householder dislikes: seamless vs. seen-less

This long-term study suggests that householders dislike the robot when it imposes cognitive burden (e.g., having to remember to turn on), and when the appearance does not look compatible with the interior of the home. In general, participants liked it when the robots operated autonomously, and required the minimal human intervention. Households that adopted scheduling functions told us the best part of the robot experience was that it made the cleaning disappear from their minds. However, I learned that invisibility from one's mind did not always contribute to the positive experiences. The participants who relied on robots' automatic docking and departing features often forgot to clean the robot, and consequently shortened the life span. People's desire to make the robot use invisible does not limit to technical features; they also try to hide the physical appearances of the robot. The study participant in their 60's (P12) felt embarrassed to leave a vacuum in the open areas. To them, cleaning devices should be stored in a closet, but the lack of electric outlets kept the robot in outer spaces. They moved the location of the robots from the living room to the bedroom if they hosted guests. P23 (single, 39 yrs) had a high-end loft with metallic and glass-made artifacts throughout the homes. He did not appreciate



Figure 11: Impact of visibility of stored location: behind the couch (left) and in the outdoor porch (right)

the cheap plastic cover of the Roomba, and slowly placed it to less visible areas such as behind the couch (Figure 11: left). It made not only challenging to reach, but also less memorable to his mind. As a result, he told us that he had not used it for the last month in the study. Similarly, P29 relocated the robot from the living room to the outdoor den after the mother decided the look and feel of the robot did not match the theme of the house (Figure 11: right). Once relocated to a less visible space, the robot became out of sight and out of mind. For the last four months of the study, P29 did not use Roomba at all even though they agreed that had it stayed inside the house they would have still used it. The mother expressed guilt as if she had abandoned a child and would love to find a way to use it again. In her words: “It’s not that it looks really obtrusive, but it doesn’t go with the decor of the house. I wish some would design something like furniture looking storage...I wish it doesn’t look like you left out cleaning thing out in the middle of your floor”.

3.3.4 Summary

To summarize, the long-term study reveals rich accounts on people’s lived experiences with robots in the home. The study confirms that long-term use patterns exist, and they change as people adopt, learn and maintain the robots. Further, the study

reveals that certain design attributes within robots can lead to accepting or rejecting these robotic products. People viewed the overall experience negative when they lost emotional bond at robot breakdown, when they thought it a luxury item due to the incompatible interactions with existing environment, when they felt bored by seeing repeated and predictable movements, and finally when they forgot the presence of the robot resulting from the lack of memory triggers. However, the attempts to engage with users on a personally meaningful manner, such as customizing the look and feel and naming the robot could certainly help overcome these potential roadblocks (as also supported by the first study (interviews)). Overall, the results I obtained in these studies added value to understanding how people accepted (or did not accept) robots as a part of the households.

However, considering that Roomba is a fairly basic robot that only performs vacuuming on the floor, I acknowledge limitations of these findings. To complement the gap, I conducted an additional study to understand design requirements for broader types of everyday robots. Because few other robots exist in the consumer market, I turned toward people’s creativity and asked them to visually depict the robots they would prefer to have.

3.4 Study 4. Sketching Future Domestic Robots

In this study, I undertook a generative design study ([74, 75]). Using this well known design elicitation techniques, the approach consisted of asking individuals to visually create their ideal home robot using a variety of materials (Figure 12). I did this study with 48 participants in Atlanta, U.S. Through users’ responses, I identified commonly desired tasks that robots could assist with, and drove design guidelines that promote acceptance of these robots.



Figure 12: generative design exercise for future robots

3.4.1 Method and analysis

I chose a generative design approach to collect data because it supports gathering user’s insights by making them do as opposed to talk and being observed ([75]). Its descriptive and unstructured nature helps amplify the thinking process and reveal human needs that are often difficult to express in words ([74, 75]). Considering the unusual nature of the study topic (future domestic robots), and some participants’ technical naivety, I felt this method would help surface participant’s insights, needs and desires. During the study, each participant was given a large sheet of blank paper (24 inches by 18 inches) and asked to create visual description of their ideal domestic robot without considering any technological constraints. To help the study participants, I provided a range of generative tools such as magazines, colored paper, pens, and so forth. I did not encourage writing unless they did it for labeling their creations. People expressed their visions of future robots in various ways. Some drew a robot with detailed functionality, such as an LED panel for human-robot interaction (Figure 13:left). Others created a collage of desired functions such as using a smart phone image to explain that the robot organizes their schedule (Figure 13:right). The goal here was to use this visual approach as props to support in their ideation process of creating a future domestic robot.



Figure 13: Generative Design Style: a Hand-drawn Robot (left), and a collage of images that contains desired functions (right)

When participants had finished, I asked them to explain their robots. This included asking them about the overall concept and motivation for the robot, and then turning to detailed descriptions of function, forms, interactions, and anything else the visual diagram suggested to us to ask. I audio-taped and video-recorded participants' narratives, which I subsequently transcribed and analyzed. I used qualitative analysis methods because the study data contained unstructured and narrative information. I first extracted 99 discrete tasks that people want a robot to perform from the transcripts. Then, I began grouping them using an affinity diagramming technique, an inductive analysis that categorizes similar key points to identify overarching issues in a given context [9]. During this process, I used the domestic tasks defined in the "Dictionary of Occupational Titles" (a U.S. Labor Department standard for categorizing domestic services) as an index for categorization. I did this to increase validity in the analysis process by keeping the inductive grouping closer to the existing taxonomy of domestic services. Also, it allowed us to identify what types of labor people would feel comfortable to have a robot replace. However, I did not limit the data to the existing list of domestic tasks described in the dictionary. People also created new tasks that relied on their robots' computational capabilities, such as germ detection and protection from identity theft. this inductive process continued

until I had grouped the identified tasks into three broad categories: Time-consuming Drudgeries, House-sitting, and Personal Attendance. Once I established these three categories, I analyzed the transcripts again to identify design implications including, form factor, interactivity, intelligence, operation, sociability, and environment.

In both countries, I had 48 participants (22 men and 26 women, mean age=42). I would describe 25 of the study participants as technical, meaning they had received professional or academic training in engineering-related fields, or reported having technologically-oriented hobbies such as hacking. No participants owned any domestic robotic appliances. They had various types of occupations including restaurant owner, nurse, professional cleaner, homemaker, hair salon owner and more.

3.4.2 Results

In this study, participants reported 99 distinct tasks that they wanted robots to perform at home. Some of participants imagined automating manual labor, such as loading dishes into dishwasher and sorting laundry. Others wanted expert knowledge, including vehicle maintenance and medical diagnosis. Figure 14 provides a list of individual tasks preferred by the study participants. All of the study participants wanted a robot that performed more than one task, which P2 described as a “Swiss army type” of robot. According to them, multiple functions increased motivation for adoption and justified the potential cost. In this section, I discuss the three groups of robot tasks, Time-consuming Drudgeries, House-sitting and Personal Attendance in an effort to inform the designer of multi-functional robots.

I present these three main tasks, starting with time-consuming drudgeries. *Time-consuming drudgeries* include tasks related to cleaning, yard work, and cooking (refer to Table 9 for some but not all examples of tasks under this domain). The study data suggest that this task domain was the most desired one. The number of tasks under this domain appeared 103 times during the interviews, outnumbering the other two

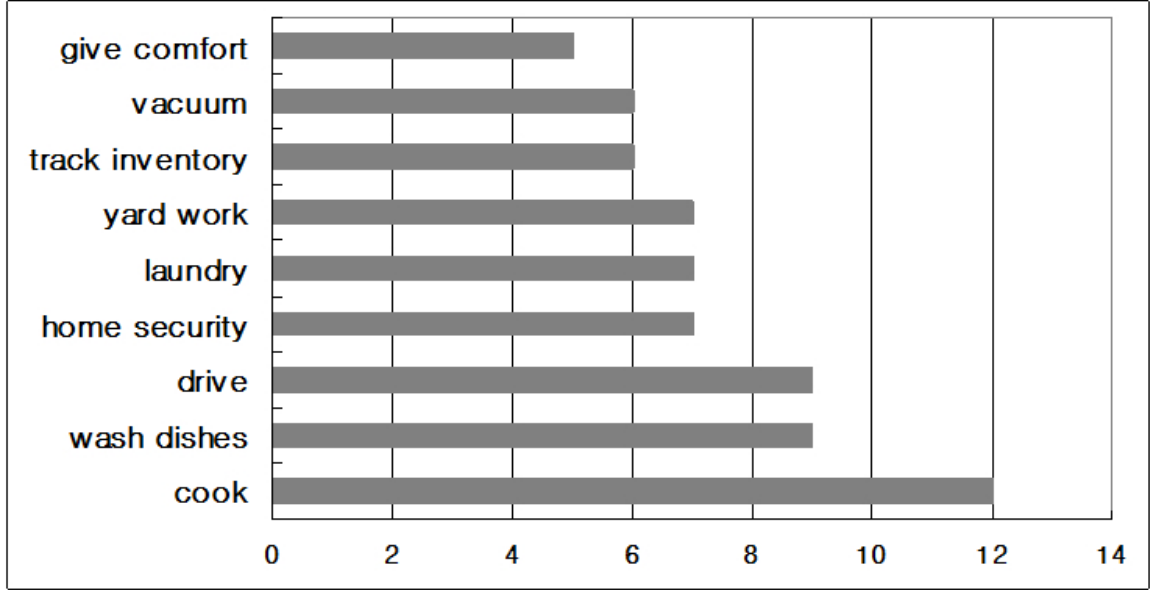


Figure 14: Individual Tasks Preferred by Participants

categories almost twice as much (House-sit appeared 50 times and Personal Attendance appeared 62 times). All but three participants ($n=45$) mentioned at least one type of time-consuming drudgery as a desired robot task.

Table 9: Some Examples of Tasks under Time-Consuming Drudgeries

Main Tasks	Sub Tasks
Cleaning	vacuum ($n=6$), wash dishes ($n=9$), laundry ($n=7$), clean tub ($n=4$)
Yard work	gardening ($n=7$), watering plants ($n=3$)
Cooking	cook ($n=12$), food preparation ($n=5$)

Participants desired robotic assistance with the seemingly “endless” drudgeries to regain time for activities they enjoyed such as playing with children and pets, and self-development through study and work. Even those who hired cleaning services saw the advantage of having a robot because they would not feel guilty for making people do the work they found “unpleasant” and “boring”. For participants, multi-functionality seemed a key factor for adopting robots that performed time-consuming drudgeries. The study participants who had professional cleaning services expressed interest in replacing the human service with a robot one only if it provided equal

or greater number of tasks. In addition to performing multiple functions, users also wanted it to do things that are difficult such as cleaning air ducts, under furniture, and ceilings. For example, P20 describes how such a robot could save time. “(P20-man)and the flexible arm will be able to fix sink because it took me two weeks to find the right tool to reach to the loose washer and be able to tight the sink”. Of course, the study participants understood that more functionality would mean higher costs and potentially lead to a larger sized robot. To resolve this, some suggested making robots compatible with existing tools at home. For instance, P2 and P7 designed robots that had connectors to attach to the vacuuming hose for cleaning and water pipe for watering plants (red circle in Figure 15). By connecting to existing appliances and tools, participants felt they could retain their desired robots (size and shape) and increase functionality. Also, thinking about cost and custom needs, P13 suggested a modular robot, with optional attachments.

As much as people spoke of automation of time-consuming tasks, they did not want too much robotic intelligence (also referred to as decision-making power). This was especially true for the tasks that required expert knowledge or involved safety risks. For these tasks, people stressed wanting to work with the robot as opposed to having the robot conduct the entire task. For example, householders wanted to create their own recipes, but have the robot perform tasks like grilling and boiling. Men appeared to be more sensitive about this issue. For example, a wife spoke about how a robot could help with “light cooking” while her husband stressed that it would only assist in simple food preparation: “(P27-man)I intentionally said easy food things. I don’t know if I would trust a robot with a knife and chop things but very simple preparation... don’t want to risk if something goes wrong”. Participants also wanted time efficiency in the mode of interaction for these robots. They strongly preferred speech (i.e., voice commands) and auditory feedback as the main means of interaction. One participant (P12) drew ears on a robot to represent the importance

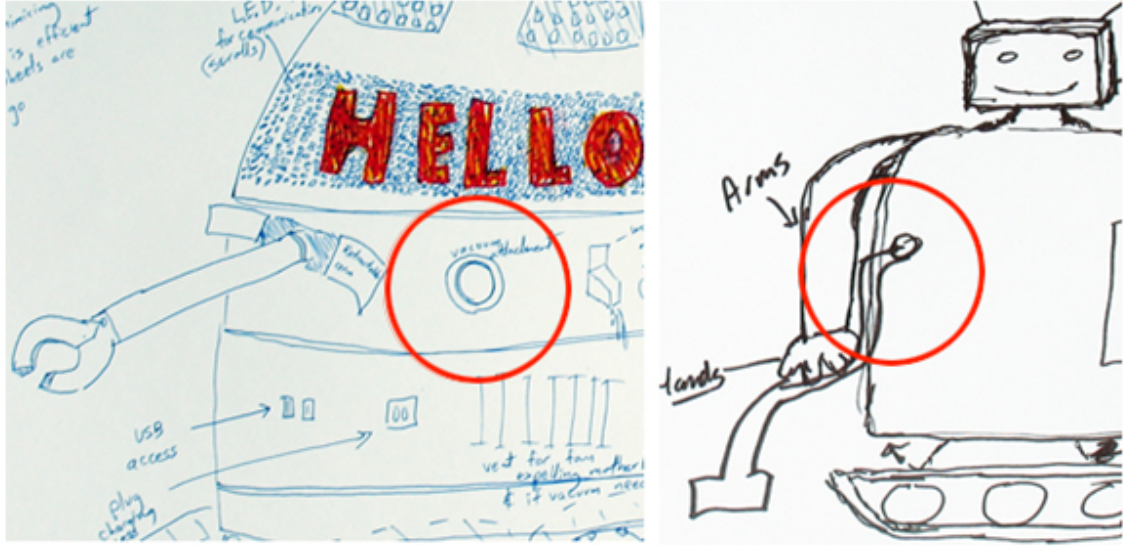


Figure 15: Depiction of robot’s connector to existing tools

of this modality. Another reason to prefer audio interaction was that people foresaw their robots being in places (like the ceiling and gutter) where they could not press buttons.

The second common tasks are *house-sitting* related. Participants relied on robot’s sensing capability and computational superiority to support house-sitting. The dictionary of occupational titles describes a house sitter as someone who oversees a home to maintain order and security of the property. For a robot, the study participants described three types of tasks as desired functions: hygiene and health inspection, resource management, and security control (refer to Table 10 for more detail).

Table 10: Some Examples of Tasks under House-Sitting

Main Tasks	Sub Tasks
Hygiene and Health Inspection	health diagnosis (n=3), germ control (n=3)
Resource Management	inventory cataloguing (n=6), temperature and light control (n=3)
Security Control	property security (n=7), answer door (n=3), body-guard (n=2)

People desired a house-sitting robot to maintain a healthy and hygienic home

through monitoring what can not be seen by the human eye: germs and allergens. Also, the study participants wanted robots for detecting health concerns such as high cholesterol levels and communicating that to doctors to get further instructions. Here, I encountered a tension between not wanting to give the robot too much decision-making power and still wanting to make it intelligent to do the task. That is, people wanted the robot to be able to perform health checks by collaborating with some medical establishments to reduce unnecessary doctor visits, but always in consolation rather than autonomously. One elderly participant (P18) spoke about a robot that could detect an emergency situation for her and make the necessary 911 call. However, she did not want her robot to administer a medical treatment.

Also, participants wanted a house-sitting robot to manage resource consumption including light, temperature and water usage, particularly during their temporary absence. In addition to this home automation functionality, people wanted robots to catalog household inventories to prompt them when things expired or needed restocking. On asking whether they would want a robot to shop based on this inventory information, only one out of six participants positively responded. Others thought tracking inventories was enough since they wanted support with information compiling process that took time and effort.

Furthermore, participants imagined a robot that could monitor their physical property. In most cases, participants wanted a robot patrolling the house (both inside and outside). Like the health monitoring robots, people spoke of a systematic collaboration between mobile robots and surveillance systems in the house as a preferred mode of operation. P4 described a robot that roamed around the house to clean in normal mode but would pull out a weapon when the security sensor in the house detected abnormal vibration or sound (Figure 16). P4 was unusual; the other six households who described a security robot did not want the risk of having an armed robot. Instead, they spoke about their robot as having a loud alarm or being

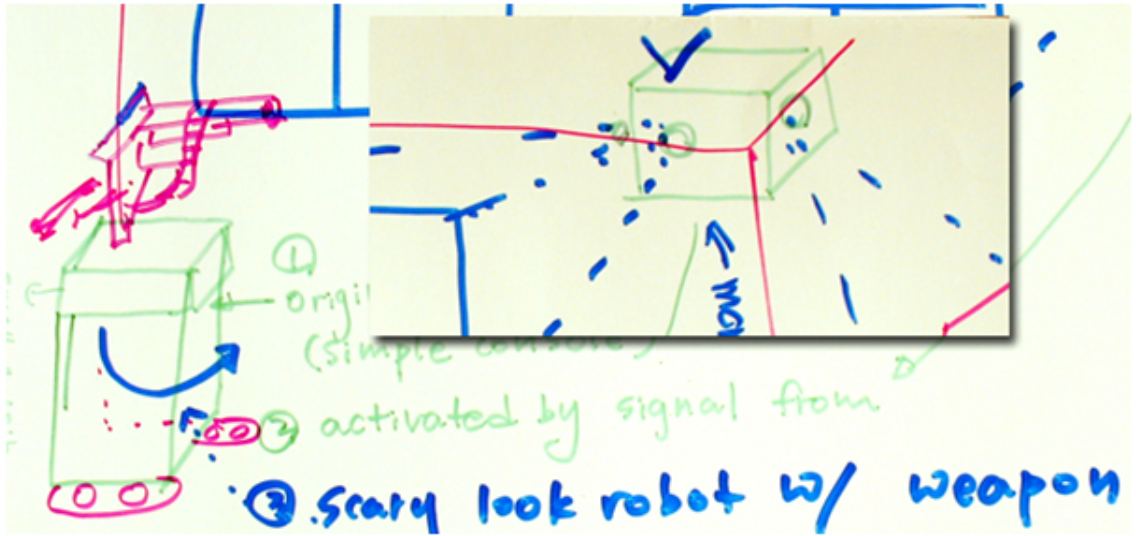


Figure 16: P4’s security robot that collaborates camera on the ceiling. The wheel and gun disappears when inactive, making it look like a fixture.

able to contact security agents.

The key design factor for a house-sitting robot appears to be the robot’s capability to collaborate with other units in a systematic manner. For instance, a house-sitting robot needs to collaborate with a cleaning robot to disinfect the germ detected area, or arrange communications with health establishments and security agents for necessary aids. Further, participants spoke of a way to interact and communicate with the robot such as remotely viewing the activity log as it would run frequently during their absence. Thus, householders certainly wanted a house-sitting robot more intelligence than one that performs a repetitive manual task, and foresaw collaboration with an existing system or a robot as a way to maximize its utility. Participants did not pay much attention to the aesthetic quality of this house-sitting robot. However, they desired flexible form factor to serve both indoor and outdoor security assistance. For example, people wanted to take the robot outside as a bodyguard, describing its form as strong and tough, such as that of “Darth Vader” from Star Wars. However, they insisted that it should metamorphose into an eye-pleasing form when inside the home such as “Nicole Kidman” (Figure 17).



Figure 17: P9's bodyguard robot that looks intimidating when outside but changes to an eye-pleasing form when at home.

The third and the last task domain is to use robots as a *personal attendant*. According to the dictionary of occupational titles, a personal attendant serves a need such as managing wardrobes, serving refreshments, applying cosmetics and more. The study participants wanted personal robotic assistances in two types: intellectual and emotional support (refer to Table 11 for more detail).

Table 11: Some Examples of Tasks under Personal Attendant

Intelligent support	
Organizer	report news (n=7), scheduling (n=3)
Instructor	financial help (n=2), fitness trainer (n=3)
Emotional support	
Beauty Support	hair and make-up (n=6)
Mind Relaxation	massage (n=6), refreshments (n=5)
Entertainment	conversation and joke (n=4), play movie and music (n=3)

Participants desired robotic assistance with intellectual support such as efficiently managing and organizing information. They wanted a robot to filter out interesting news, and search and compile information on demand, such as product user reviews.

P20 highlights this robot as:“(P20-woman) if we are looking a new product, (it would) go and get all the reviewthat sort of tedious and time consuming information compilation tasks. Again, it’s not about decision making but automating some of the time consuming tasks”. But others sought robotic support in more complicated tasks than simple information parsing. Ten participants depicted a robot that could instruct them with specialized knowledge, such as financial investment, fitness maintenance, and child education. Further, participants illustrated a robot that supported them emotionally. The study participants, particularly women who lived alone described a robot’s assistance in improving their mood through serving cocktails and sweets, and assisting with beauty care including, pedicure, hair-care, and makeup. In addition to these services, people wanted a robot companion who could tell jokes and share conversation in deeply personal matters.

For these robots performing as personal attendants, the study participants seemed open toward having a smart robot, even to the level close to human intelligence. Two participants expressed that this type of a robot should reinforce their intelligence by offering information beyond their expertise, such as teaching how to invest money and tutoring math to her 6-year-old granddaughter. However, even in these more intelligent and autonomous robots, householders did not want the robot to have the power of decision-making, such as being able to buy and sell assets. Personal Attendance appeared as the only domain that participants spoke strongly of robot’s sociability. People wanted to live with a friendly robot that they would want to keep around for a long time. However, householders clearly stated that they did not want a robot that acted as a friend but as a professional butler (as also reported in [20]). They associated friend-like actions as potentials for not acting politely and being less dedicated to the task. Also, participants envisioned that the personal attendant robot should have social skills as they wanted it to help with hosting guests by engaging in conversation and telling jokes. But they rejected the idea of

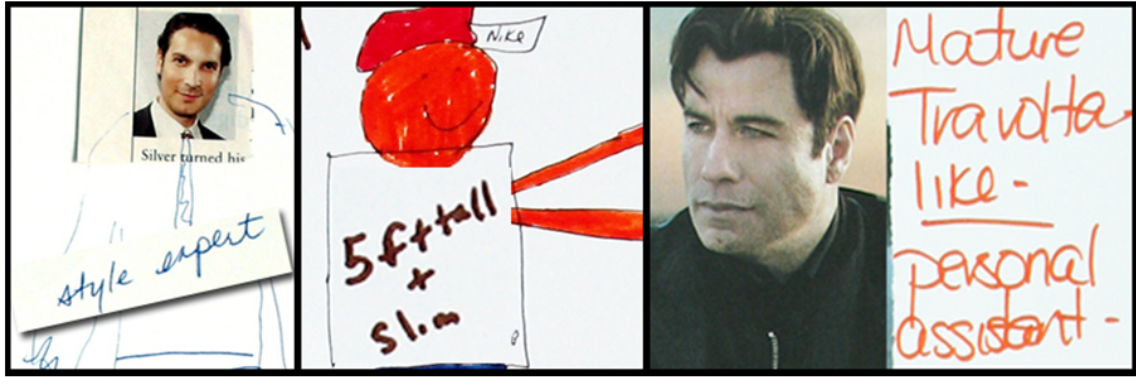


Figure 18: P1’s professional yet good looking butler robot (left), P11’s do-it-all robot that dresses nicely and has a slim figure (middle), and P10’s personal robot that has the mature John Travolta look (right)

more intrusive means of entertaining, such as singing and dancing. In a word, people valued a robot’s capability to act socially with subtly. In addition to sociability, the study participants actively discussed about form factor. They expressed specific preference including gender, size, and aesthetic qualities for personal attendant robots (Figure 18). Whether the robot took an anthropomorphic form or not, people agreed that a robot could provide a comfortable and eye-pleasing form beyond “older notion of servant or housekeeper (P23)”, such as a humanoid robot wearing a maid uniform. The wife from P25 discussed that the aesthetic quality was important to get engaged with the robot and to keep it around for a long time.

Householders spoke of emotional comfort and pleasure not only in the form factor, but also in the mode of interactions. P25 stressed the importance of having haptic interaction modes as people normally touch and pat to show affection. Also, P8 reported that a robot’s ability to speak in natural human tone was critical particularly when educating children so that they would not only feel comfortable with robot’s presence but also have respect for it as they would do with a human adult. Finally, this domain exhibited an interesting gender disparity. Out of 15 participants who mentioned at least one task belonging to Personal Attendance, 11 of them were women. More specifically, any tasks that reinforced emotional support, such as giving

massage and assisting with beauty care all came from the study’s female participants.

This study surfaced interesting design lessons that could add to or confirm the findings from Roomba studies. First, it showed that people less cared about how anthropomorphic it appeared but how it looked compatible with the home which was also the finding from the studies with Roomba. It led people to create robots with modular customizations and morphed shape. Also, they talked about holding manual control of the robot particularly if it performed more complex tasks that could involve safety issues. The Roomba studies present similar findings that people wanted manual control over fine navigation patterns of the robot for more efficient cleaning paths. Furthermore, it shows that personal values greatly influence the expectation for robots, which I did not see in the Roomba study. I saw different needs and desires between men and women; men wanting robots that are more compliant and subservient whereas women wanting robots that can become companions or intellectual mentor.

3.5 Design Implications

Thus, I have explored the lived experiences with robots (study 1, study 2, study 3) through the use of Roomba, and learned people’s desire for future living experience with domestic robots (study 4). Collectively, these studies inform that robot acceptance and rejection do not depend on specific form factor (i.e., humanoid look and feel) or highly sophisticated intelligence. Rather, robots become accepted when appearing compatible with the surrounding environment, promoting social and emotional bonds among the household members, and balancing the automated amount of tasks against the work put on robot maintenance. In sum, these studies shed insights that *environment, social actors and tasks* are the three key attributes to consider when designing robot experience for the home. In this section I reflect on how each attribute influenced the robot experiences at home, and how these need be addressed

in design.

3.5.1 Designing for environment compatibility

Reliable and smooth operation has always been important in household technologies (e.g., unstable connectivity, limited coverage) [6, 26]. With robots, my studies show that this design agenda may become more complex because robots directly interact with physical spaces. For everyday robots that may sit between smart technologies and home appliances, people expect that they perform reliably in various types of physical home spaces without having breakdowns. Participants often compared the lifespan and performance characteristics of their robot with those of manual vacuums. And when Roomba displayed less durable performances, it diminished people’s motivation to take good care of it. The participants who showed strong emotional bonds even felt betrayed when a robot stopped working, and consequently ceased to use it at all.

Throughout the studies, I learn how much householders pay attention to the aesthetics of their homes. They described how they thought about purchases of furniture, paintings, and other objects to go with a theme that they wanted their house to project (e.g. modern, comfortable). Robots remained as a visual element in this planned physical environment even when they were not used, and householders cared about its aesthetic compatibility with the rest of the house—as pointed by other senior-care robot study as an important design attribute [31]. Further, because robots move around the house they are likely to stand out in the environment anyways. However, my study suggests that standing out in use can become acceptable as it provides a series of cues about how the robot works. Rather it is the location where the robot is stationed that seems more contingent on appearance and form. One easy solution the long-term study hints was to allow for external configuration. The manufacturer of robots can produce and encourage personalization toolkit to help

make their robot blend into their home environment, such as applying a cover match colors of wood floors. The generative study (Study 4) suggests more ways to increase a robots' visual compatibility. The study participants suggested a flexible form factor that morph into a different form (e.g., a decorative fixture) in order to make the machine "fit in" when not in use and morph again to make it "practical" when in operation. People further discussed this flexible form in foldable and modular units as a way to easily store and carry it on a trip. Failure to reflect the visual themes in the home may lead people to discontinue using it regardless of their satisfaction with functionalities. My study sets an example. When Roomba did not match with householders aspirations for their home look, they moved the machine into a less visible location and subsequently forgot to use it.

3.5.2 Designing for bonding with social actors

The study results show that people form intimate relationships with their robots in the ways that were not as frequently identified with other domestic technologies. My study illustrates examples including, the attitude change toward vacuuming as a fun activity, ascription of life-like attributes, active promotion, and environment modification. People spoke of happiness with Roomba because it positively changed their attitude toward cleaning from drudgery to a fun activity. As the use was considered fun, the work required to use Roomba, such as monitoring and rescuing the robot, and clearing off the floor. Also, people engaged their Roomba by ascribing it life-like and social characteristics. Many saw their Roombas as somehow cognitive and physical as well as having a personality, name and gender. This in turn helped them engage sufficiently so that they could talk and write about it, through which I argue, they formed a relationship with their robots. Further, people valued their Roombas and consequently took pleasure in demonstrating it to others. The study 4 confirms that it may be the case with other robots. Participants named the drawn robots and

naturally referred to them in gendered way. They even desired to engage with robots in social and emotional activities, such as dancing together, making jokes on a sad day, and playing games for entertainment. In addition to the direct bonding with the robots, my studies show that robots can promote the social dynamics among the members in the households. Study participants used Roomba as a conversation or show-case piece to friends or visitors of the home. The biggest changes in the social dynamics was how the roles played by parents and children have changed at least to the extent they perform drudgeries. The fun perceived from robot use made this activity voluntary and pro-active for children, which released the tension that normally existed in the homes with parents and teenage children.

Further, I learned that these strong social and emotional bonding are largely dependent on certain personal values. In the long term study, householders limited children's use when they felt relying on a robot could hinder the opportunity to learn the skills associated with manual cleaning tasks. Also personal values perhaps induced by the existence of pets and children, or gender differences influence how people adopt and accept robots. The survey shows that households with pets and children that can engage with robots in fun-oriented activities such as Roomba racing showed higher satisfaction toward robot's performance. And the generative study (Study 4) hints the contrasting needs between genders in desired robotic tasks and the design specifications. In general, women tended to seek a robot that could provide support to promote the quality of their lives. For instance, women described a robot to complement the lack of their physical and intellectual capability, such as tutoring math to their children. Indeed, the Personal Attendance robots that provided intellectual and emotional support were heavily comprised of women. Accordingly, they desired robots' forms to be appealing enough to keep closely around. In contrast, men wanted a robot to execute and serve their orders like an apprentice or a servant. The desired tasks included tool delivery and food preparation according to the recipe

instructed.

3.5.3 Balancing between autonomy and control in task performance

I infer from the strong body of evidence that most existing smart home technologies elicit strong positive responses when they are integrated into people's lives and become invisible in use [88]. I found that the case for robots appeared more complex: robot design should carefully balance between blending in and standing out to provoke sustained use. Study participants expected the robot to act independently and take over the labor. The level of perceived autonomy increased when they felt it managed the overall cleaning process, such as running unattended and starting from and returning to the home base on its own. Moreover, people saw the robot more as an independent agent when it could perform tasks that were far more difficult for humans such as cleaning under couches and beds. The generative study (study 4) supports this; participants desired robots to serve the tasks beyond their capability, such as reaching higher and lifting heavier objects. People valued robot's agency and independence because they saw it as the means by which they acquired time for other activities such as playing with children. However, the study findings suggest that the design of domestic robots needs to provide a certain amount of human control over a robot's intelligence. As much as people wanted the robot to perform tasks with quality without supervision (i.e., working autonomously), they desired to assure its compliance by restraining the decision-making power. The desire for human control appeared stronger if a robot's performance could risk human safety, such as using knives and drills. As a result, people chose to work with robots rather than having it conduct the entire task, such as sensing and alerting abnormal conditions of the home but not taking any direct actions against it. Even for a robot that had a high level of intellectual and emotional capabilities, participants desired a way to control, such as being able to turn it on and off. Participants sought compliance not only in

robot intelligence but also in its form factor. All of the study participants drew robots equal or smaller on size to themselves, associating it with obedience and compliance (also supported by [56])

If robots perform a task autonomously, it has to carry it out with critical errors; the studies highlight examples of how Discovery models became less appealing perhaps due to their error-prone docking capability. In contrast, Scheduler models were easier to adopt because of the timer function that barely made any errors. This contrast in reliability is interesting from a technical viewpoint because infrared sensing for automatic docking involves more complex technology than the simple timer feature for scheduling. My research illustrates that user satisfaction depends on how the system works as a whole reliably rather than comparing the technical complexity of each function. Of course, technologies may fail in use, particularly when they run unattended in a dynamic space such as the home.

One way to increase the perceived reliability is to intelligently support the troubleshooting process. I heard numerous accounts that people want robots to not just diagnose what went wrong, but also to communicate the status in a comprehensive manner. Based on this finding, I argue that the self-maintenance would play a critical role in the sustained acceptance of intelligent appliances. Recent robot studies implicate that the design of self-maintenance programs for intelligent appliances should carefully follow socially acceptance manners, such as conveying apology [57] and using team-play analogies (e.g., we made the mistake) [41].

Another way to increase the perceived reliability is to show an explicit progress in robots' learning, particularly in the way robot moves. Many of the reliability predicaments occur during their interaction in the physical settings. The long-term study informs that people were generous toward robots inefficient and random movements including accidents it encountered. Initially, the study participants liked the random movements. They enjoyed being unable to predict what the robot would do next,

and talked about the motion as expressive, lively and lifelike. Over time, the participants wanted it to acquire more knowledge about the environment and perform tasks efficiently as it learnt more about the environment. Further, they wanted to see the how robots learned through its progressive motion from a random to a smart path-finding system. That said, robots—even the ones equipped with advanced navigation capability—should not perhaps display this type of knowledge from the very outset. Rather, they need to exhibit this over time to build trust that it can learn and perform better like a living-being.

3.6 *Summary*

Overall the robot research implies that everyday robots should carefully balance between invisible operation and visible interaction. Robots become more accepted when they provide a durable, reliable and autonomous service. People do not want to get interrupted by the robot, and prefer it to carry out tasks unaided and free of errors. However, at the same time, they need some types of reminders. For example, they want to be reminded of its presence particularly if it was out of sight, and want to know when something went wrong including, what the problem was and how to fix it. Hence, I argue a key design challenge for robots is to balance the invisible task performance in the environment, and explicit interaction with social actors to increase adoption.

Next, I identify how I should present this vast amount of information of people's lived experiences with robots to become practical in the real-world robot development process.

CHAPTER IV

FRAMING DESIGN GUIDELINES

One of the goals in this thesis is to frame the lessons learned from the lived accounts into operationalizable guidelines for a real-world robot development. This section describes my participation in a real-world project, called HomeMate, and the application of the knowledge learned from the empirical user research. In this chapter, I first explain the HomeMate project in detail and the application of lessons learned from the empirical study. Then, I describe how I built the initial set of guidelines based on this experience.

4.1 HomeMate Project

HomeMate is an assistive robot that can support seniors physically (e.g., bringing medicine), cognitively (e.g., reminding time to take pills) and emotionally (e.g., enabling video chats with grandchildren). Concisely put, HomeMate is a senior-care robot designed to promote aging-in-place by allowing seniors to live independently. This project was motivated by the dilemma of an increasingly aging population where simultaneously the number of people who can provide healthcare service decreases [14, 54]. Aiming to deploy this robot to consumer markets in five years, this project is an ongoing effort between Korea and United States, involving two robotics companies, two robotics institutions (SKKU in Korea and Georgia Tech in U.S.) and an out-sourced design firm. Except for Georgia Tech, all other HomeMate-related parties are based in Korea. Because this robot plans to be first deployed in U.S., Georgia Tech played a role to provide research data about how American householders live with consumer-domestic robots, and lead developers with directions to increase potential acceptance of HomeMate. That said, my role in this project was to ensure

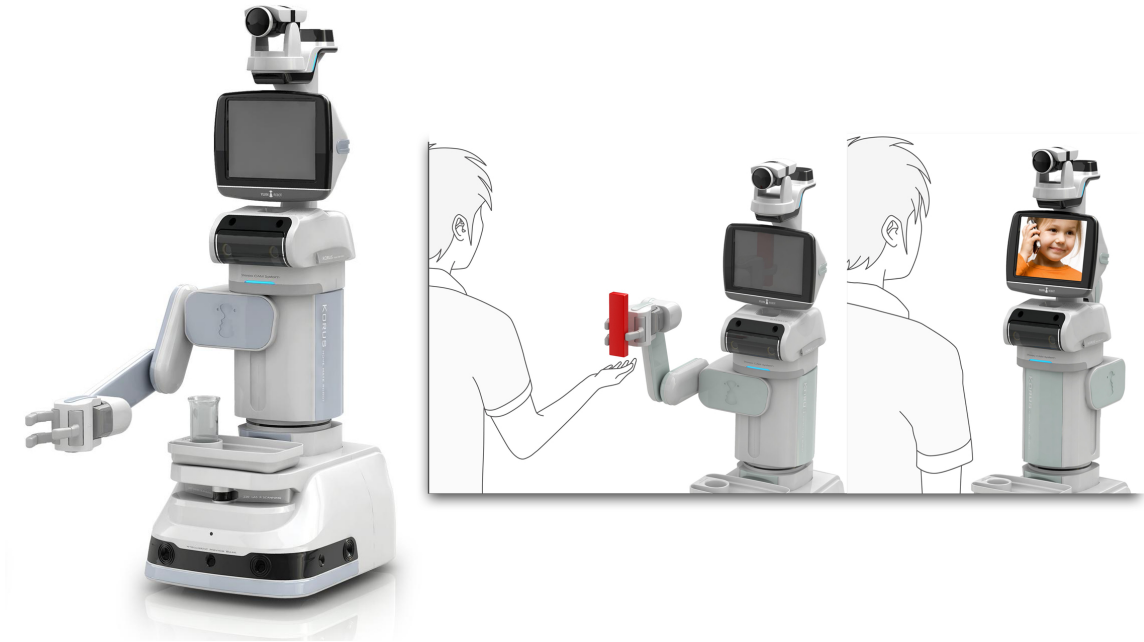


Figure 19: The latest design of HomeMate, a senior-care robot

the human-centered values in the design so that HomeMate can be accepted by users. During this process, I worked as a user experience experts, bringing in the information about how people live with robots, and trying to identify how this piece of information can best be delivered to designers and engineers. I was involved in this project because I wanted to conduct research on learning the real-robot development. More specifically I wanted to learn the existing design process of a consumer robot, and to see if guidelines might be useful and if so in what way I should frame it to better support the design effort.

The latest design of HomeMate is depicted in Figure 19. This robot largely serves three tasks. First it provides physical service such as delivering medicine and picking up dropped remote control. Second, it cognitively supports elders by reminding time to take medicine and scheduling important dates such as the doctor's appointment. Lastly, it provides infotainment service, such as allowing elders to communicate with their families through robot-embedded telecommunication system. Thus, the successful design of this robot can offer the potential to allow older people to remain in their

homes (instead of moving into costly care), and free younger people to have quality leisure time (by relieving them of domestic chores).

To date scholars have long studied elderly-care robots [14, 16, 43, 54, 31]. Despite the number of scholarly and industrial efforts focused on designing a senior-care robot, it has yet become a market reality [14]. Scholars have identified hurdles to adoption stemming from two characteristics pertaining to the elderly: resisting to adopt new technologies [14], and feelings of being stigmatized by the need to have assistive technologies [14, 54]. Considering robots’s general portrait being associated with highly advanced technologies, human-centered approach is crucial for the market success. Research is required. Existing literature provides high-level implications for how to design a) senior care robots [14, 16] and b) domestic robots [34, 85], but it remains unclear how designers can translate those implications into concrete advice for robotics development in the real-world. The observation of the HomeMate project attribute this gap to the relative novelty of designing consumer robotics and the consequent lack of design guidelines to support such an activity. Bridging this gap is crucial given the growth in scholarly and industrial efforts to provide robotic services in the home.

4.1.1 Study design

Overall, I have participated in the HomeMate project for two years from the early design development, doing a study similar to participant ethnography [48]. I joined the team as a user experience researcher with two goals: augmenting interaction experiences in the current robot design, and establishing user-centered design principles for consumer robotics. I began this collaboration by working with the development team for a month in Korea, and then remotely in U.S. to present. The month-long collaboration was crucial for the project because the team determined robot tasks and design requirements during this time, and I played the role of providing user needs



Figure 20: HomeMate’s concept ideation process

and desires for domestic-consumer robots that were primarily the summarized results from Chapter 3.

My specific roles included leading the user-experience design by drawing designers and developers together and developing use cases and interaction schematics (as shown in Figure 20). For a month, I held 16 meetings with developers (3-6 people per meeting) who came from manipulation team, hardware control team and software development team. Also, I had one meeting with product designers from the outsourced firm. During this time, I presented the results from the field studies seven times and informed how American households adopted and used robots and design considerations. These meetings allowed us to generate a series of form factor and interactions based on available technologies and human-robot experiences in the wild (Figure 20). I documented and recorded all meetings, and took daily notes about the design process including what I learned newly, and what I felt as challenges. It resulted in 23-hour-long audio recordings, and 105-page-long design documentations. These recordings helped balance my personal bias (i.e., written reflections in the diary) against what actually occurred during the design process.

4.1.2 Lessons for design guidelines

This experience deepened my understanding if guidelines are really needed, and if so how proposed guidelines can and should help the current robot development process.

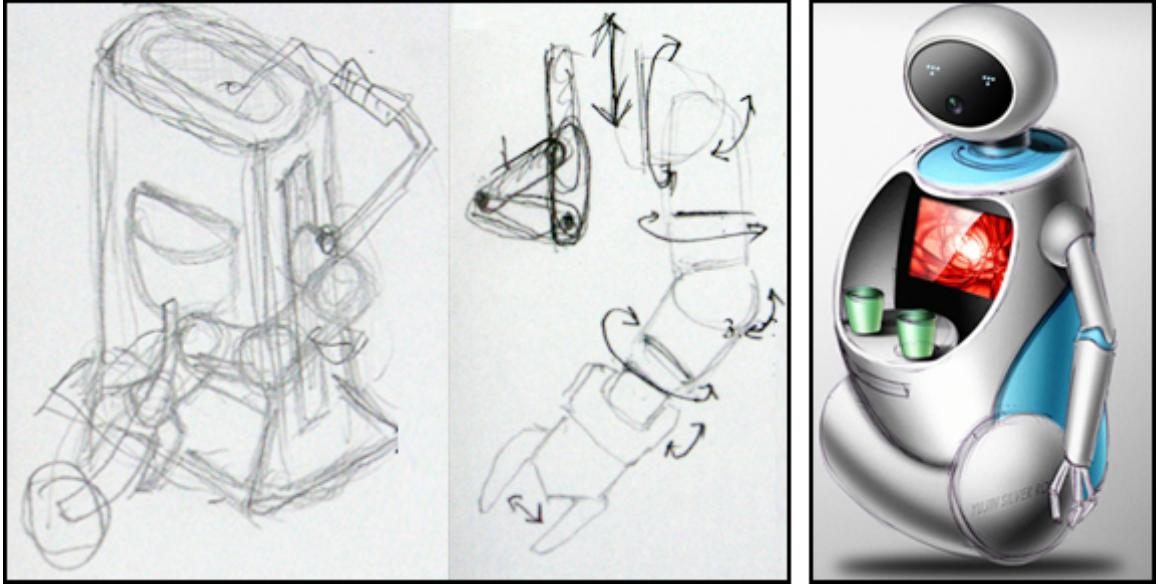


Figure 21: functional and aesthetic focus: lack of human-centeredness

The month-long participation and the remote collaboration afterwards inform that some guidelines are necessary particularly when generating the generic design concepts. Both developers and designers brought little experience in creating consumer robots. The engineers have created vacuuming robots (iclebo), edu-tainment robots (iRobiQ) and delivery robot prototypes, but they have not created a complex domestic robot that serves physical, cognitive and social tasks at once. Designers have close to zero experience with robotic products. Perhaps due to this varying degree of expertise, engineers and designers did not collaborate closely together during the concept development phase. Also pressed with time, the robotic companies (mostly consisted of engineers) initially let designers drive the concept developments during which they had made 20 concept sketches without any given design parameters (e.g., manipulation mechanism, size specs), which led them to base the design mostly from sci-fi movies and fiction. Concurrently, engineers led their own concept development, which was mostly focused on finalizing the functional specs. The motivation behind this parallel process was to expedite the design speed by designers developing the

form factor while the engineers making what goes inside. However, this process produced outcomes that were hard to merge as shown in Figure 21; engineers could not take the initial form factor designs because they were rarely feasible for actual implementation. The parallel development has been proven as an effective design process in a time pressed robot production. The Snackbot project led by Carnegie Mellon University ([56]) has successfully led the aesthetic and functional design together. They tested design prototypes with a series of short user testings and use it as a basis for developing and refining the overall design. In other words, they put forward the human-centeredness as the first priority and used it to communicate together. During the meeting with designers, they expressed frustration that user-centric approach was difficult with robot development. Few products exist that they could benchmark (in addition to prototypes being developed in the laboratory) and the designers themselves know little about what it is like to live with robots. This frustration was equally expressed by the engineers. Although they have produced consumer robots and have used in their homes, they know little about how people in general adopt the robots and in what cases it might fail to become accepted. That said, I argue that the design guidelines should provide a tool that allows developers to arbitrarily construct what it is like to live with robots in the home.

Further, the guidelines that help reconstruct the lived experiences should be introduced in the very beginning of the design process. I brought and presented the user research results to designers, but it occurred after they had already generated several design concepts. The late involvement of user data elicited the feeling that I (the user experience researcher) was trying to take control over the design work, and he designers expressed some offense by saying that the research only restates the parts they knew or have considered in the design—when their concepts were not grounded in user data but based on their inspiration from sci-fi movies.

Engineers received the user study results more positively; they showed genuine

interest in the research results. However, the research results that I presented were too lengthy for them to digest. They wanted to take the information that was only an interest to their part. For instance, a mechanical engineer asked the information about environmental constraints, such as floor types, house size and door threshold height that were directly related to robot movements. This piecemeal digestion of research results lead to another problem; few discussed how to make HomeMate emotionally and socially appealing. They unanimously spoke they were crucial, but did not know how to achieve it. One software engineer asked me to define social interaction, and to explain to him in terms of API he could use in his software. I brought in ‘social’ components by actively referencing to the user data during the design meetings. For example, I showed the example from the Roomba study how it was important for robots to appear visually subtle and compatible with the environment, and argued that the mechanical arm should at least be invisible while being stationed. As the result, designers decided to make the arm fold backward so that from the frontview, the robot would appear less mechanical (Figure 22:left). Also, the initial technical spec included the robot’s arm to grab objects only on the table height. I presented research result in [16] that seniors want the robot to pick up remote on the floor more than to bring glasses on the table, and discussed that it was essential for robots to show larger height adjustment. As the result, HomeMate’s manipulation specification has changed to move up and down enough to grab objects on the floor (Figure 22:right). This informs that the guidelines based on user data can help orient the design to become more human-centered. Further, the guidelines need to be organized in the way that designers and developers can obtain the right information without having to go through the user experience researcher. Through the month-long observation, I learned that designers and developers take a certain order in creating robots. They first determine hardware specs, such as general form factor, the placement of an arm, the computer (robot brain), and more. Once those

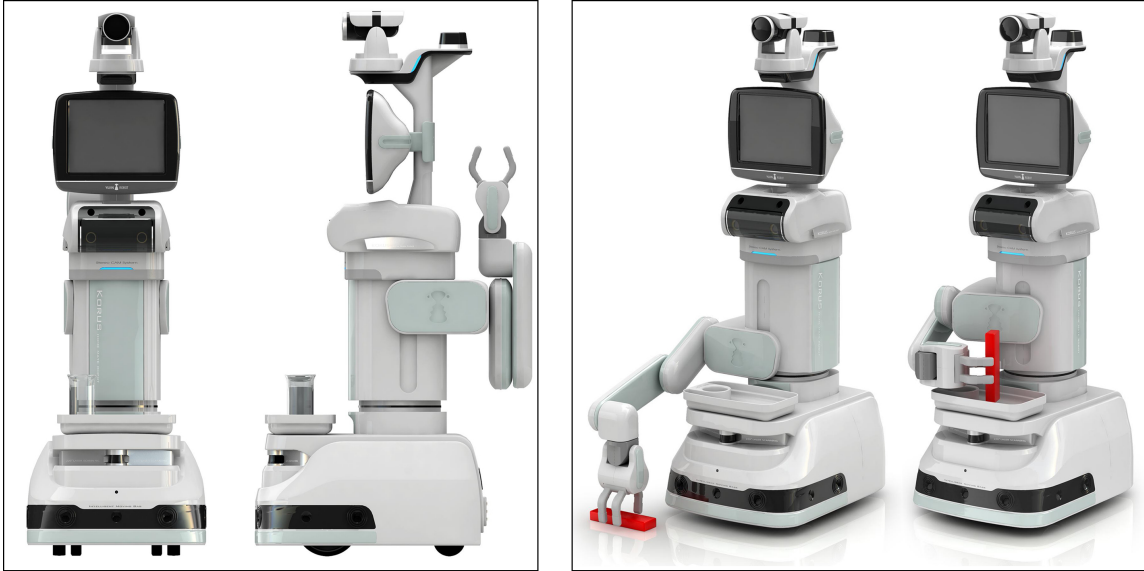


Figure 22: left:homemate’s foldable arm when not in use, right:homemate’s height adjustment

specs are fixed, they develop software-related specs including what input and output modalities they would use to control the robot and receive the feedback from the robot. Once, they have established these functional parts, they began to think about social/emotional components that can engage robots with people—frequently referring to it as arbitrary social module that they could fit into the software module. Gathering from this experience, I organized the design findings from Chapter 3 into three dimensions: operation dimension that includes guidelines about form factor and manipulation, communication dimension that employs guidelines about input and output modalities, and finally engagement dimension that is specifically dedicated to inform how to make the robot socially and emotionally appealing because this part is where the developers are most unfamiliar with.

To summarize, the participation in HomeMate design process shed lights on two large implications for framing the lived experiences with robots. First, the guidelines need to provide a tool for designer and developers to re-construct the lived experiences to mediate the absence of their own due to the novelty of this product. Second,

the guidelines need to be organized in the way a) designers can quickly draw the information necessary to them and b) developers can learn about how to implement social and emotional interactions in the design. Based on these two insights, I framed the research data presented in Chapter 3 into an initial set of guidelines. I introduce them in the following section.

4.2 Introducing Design Guidelines

In presenting design guidelines, I suggest two steps (depicted in Figure 2 in Chapter 1: page 10).

- First, designers need to understand broader contexts of how a robot would interact with the environment, people, and other artifacts in an everyday setting. To better explain this holistic picture of the interaction, I present a theoretical framework, called Domestic Robot Ecology (DRE).
- Second, I provide actionable design guidelines that designers can refer to as they create robot interactions, such as how it moves in a certain environment. I divide these guidelines into three dimensions: interactions for robot operation (e.g., mechanical structure and form factor), interactions for robot communication (e.g., dialogues), and interactions for social and emotional engagements. These levels reflect the order of interactions related to low-level and mechanical operations, interactions related to controlling those operations, and finally interactions related to enriching the interactions. I did so to allow designers to better structure the complex nature of the robot interactions.

The first step helps designers and developers who are unfamiliar with robotic experiences in the home construct high-level interaction experiences to forecast general design requirements and use cases. Then the second step allows them to drawing more specific action items (e.g., software requirements and form factor specs) that they can pursue to create a working prototype

4.2.1 Step 1: Framing holistic experience

The first step in the guideline is to frame “holistic” experiences potentially elicited by everyday robots. This step is crucial because few people know this experience unlike a cell phone or a personal computer that has penetrated the mass market, and robots by their nature of active agency are complex to depict based on assumptions. Studies on lived experiences with robots (e.g., [34, 32, 55, 53]) report that robots are organically connected to the everyday spaces as they interact and influence the physical settings, the social actors, and the related activities all together.

I began drawing the holistic experiences based on the three attributes and their inter-connections to robots (described in Section 3.5). More specifically, I was trying to identify how robots shaped relationships with them. During this process, I felt the need to keep the relationships consistent across three attributes. I labeled the relationships using the three social roles of robots as a tool, a mediator and an agent proposed by [19].

The shaping and labeling of the relationship between robots and the three attributes made me realize that environment, social actors and tasks are tightly coupled to each other. No relationship existed without the influence of the other attributes, again confirming the importance of incorporating these factors into the design. For example, the physical changes Roomba bring to the ‘environment’ such as bumping into pets and hitting the furniture in random paths elicited the lifelike personalities and deepened the emotional ties with ‘social actors’ in the home. But with written labels, it quickly became complex and hard to digest at a glance. So I utilized Forlizzi’s Product Ecology [33] as the base framework and drew how robots and the three attributes were inter-connected. I placed robots at the center because it was the critical piece, and positioned the other attributes at the peripheral of the frame. Consequently, I could make the initial five relationships robots and the three attributes formed, which crucially influenced the acceptance or rejection of everyday robots.

Simply put, I created a tool to depict the relational and holistic view of robot interaction with domestic environments, referred to as DRE (Figure 23). The visual representation made it easier for me to grasp the holistic interaction experiences of everyday robots.

And I took a further step from there to capture how these experiences change over time. For each temporal stage (pre-adoption, adoption, adaptation and sustained use), I highlighted the relationships that largely impacted the experiences. That said, DRE is the outcome of my continuous effort to capture how robots shape relationships with attributes in domestic spaces over time in a clear and comprehensive manner. I particularly chose the term, ‘ecology’ inspired by [33] to emphasize that my framework shows a holistic view on the interaction experiences that robots create over a long-term period. A design framework by definition refers to a theoretical explanation that articulates the phenomena involved in a design problem, and the relationship between those phenomena [33], which according to [37] can be interchangeably used with the term, a theory. Researchers state that the use of the framework-based design can bring benefits with three respects. First, it helps articulate the complex nature of real-world interactions, and hence facilitates better collaboration among designers from multiple disciplines by sharing a common ground of context [33]. Second, the framework can help the design less driven by designers’ intuitive and prescribed notion of how things should be, and make it more grounded on the research-based user data [33, 37]. Third and finally, a framework can provide a solid ground to solicit ideas and concepts for the developers who are new to the design problem [42, 33]. Considering the short history of the commercial application of domestic robots, many designers will feel the design challenge relatively new.

First, DRE depicts the holistic and relational view of the robot interactions (Figure 23). It allows designers to easily project how their design choices would influence the overall user experience. The study findings (presented in Chapter 3) show that

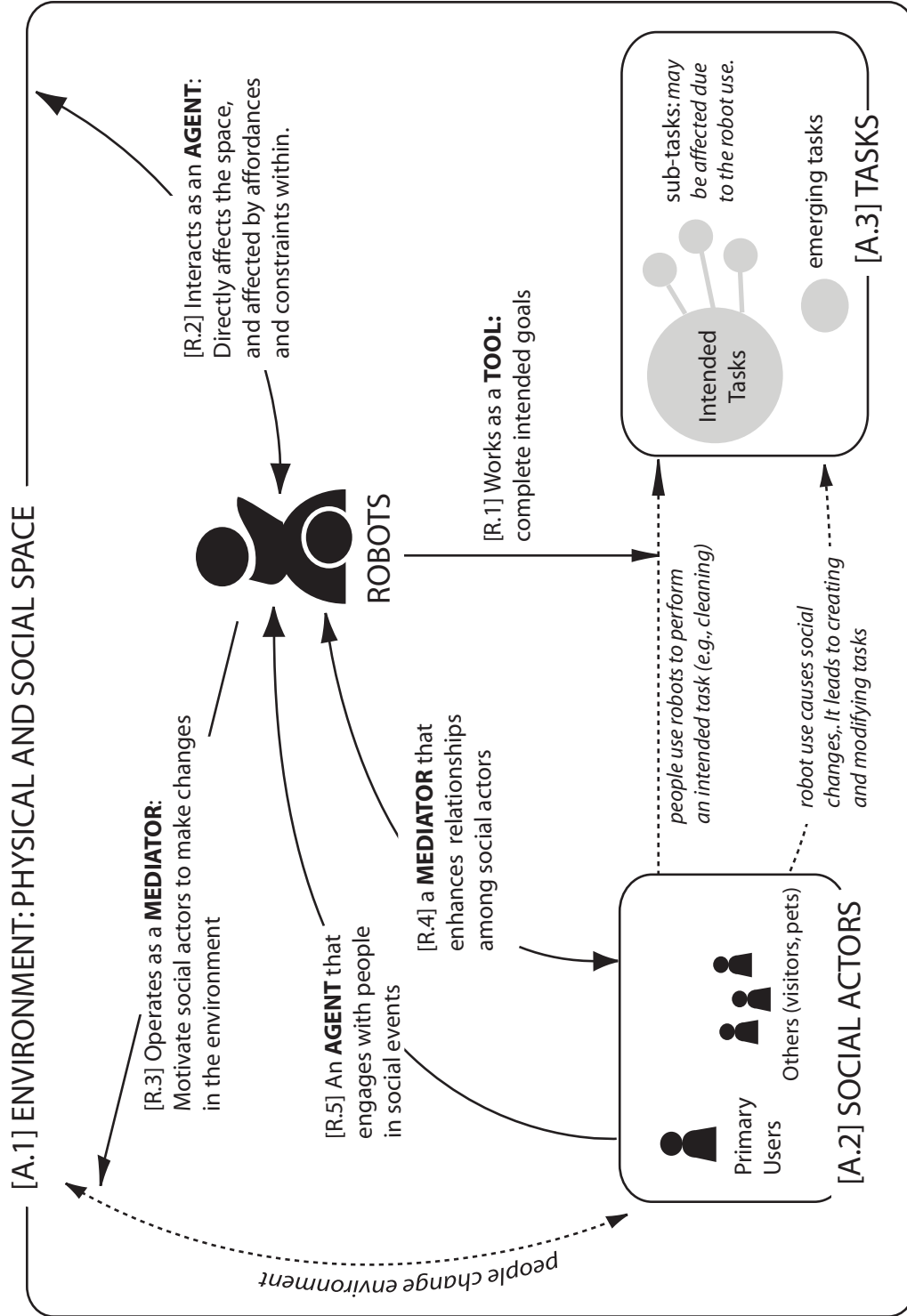


Figure 23: Domestic Robot Ecology (DRE), the holistic interaction experiences with everyday robots.

robots elicit dynamic interactions with physical space, household members, and intended tasks. These relationships are inter-connected and relational to each other. Briefly, this framework shows three key attributes —physical and social space, social actors, and designated tasks— that largely influenced the interaction experiences.

A.1 *Physical and social space* provides a platform for interactions to occur. Venkatesh et al. describe that today’s home comprises physical, social and technical space [92]. Physical space refers to the indoor environments, such as floors, rooms, and furniture within. Social space refers to family lifestyle and activities that constitute an important part of the domestic living. The studies in this thesis show that robots do affect this social space as people share stories, photos, and videos of their robot experiences [86]. Technological space indicates the total configuration and organization of technologies in the home, such as the location of their placement. I contend that the technological space for robots virtually overlaps with the entire physical and social space. Unlike screen-based computing technologies, robots have ubiquitous spatial presence because they move autonomously in various parts of the house [55, 95]. That said, robots elicit impacts in broader physical space. Also, robots can intelligently respond to people, and establish connections on their own, which can consequently increase the opportunity to get involved with social activities [52]. Therefore, I suggest that the technological space of domestic robots should be understood with physical and social spaces altogether.

A.2 *Social actors* are the living members in the home, such as householders, guests, and pets. Existing studies classify home technology users into two groups: internal members (e.g., family) and external members (e.g., visitors and friends) [92, 42]. However, studies have shown that household technologies, particularly

appliances are not used equally among internal members (most notably examined in [17]). It led us to reflect on social actors not by who live in and out of the house, but who actively use and did not use the target technology. That said, I divided social actors into two groups: 'users' who interact with robots on a regular basis to complete a task, and 'non-users' who do not regularly use but engage in social activities with this technology. I note the inclusion of pets as a part of social actors. Similar to how children's involvement increased the adoption of digital technologies [90], pets' lively responses and active interactions with robots play an important role for householders to accept them. Previous Roomba studies show that pets followed around the moving robots, and even learned to get a ride on them, which increased people's positive responses [81, 86].

A.3 *Tasks* refer to the activity that the robot is designed to serve. Domestic tasks are closely inter-related and have unclear boundaries from each other [26], and therefore automating one task by using a robot may bring substantial changes to the connected tasks. In addition, the use of robotic products may emerge new types of domestic tasks that did not exist before prior to the robot adoption. Taking Roomba use as an example, householders created leisure activities such as creating a race track to compete with neighbor's Roomba [81].

As robots interacted with these attributes, various types of relationships incur. five types of relationships occurred during the long-term acceptance. Robots form a relationship as:

R.1 *A tool* to perform tasks: robots served as a utilitarian tool to replace the manual labor, and to improve the quality of life. The studies in this thesis shows that people value the robot by the amount of labor it replaced/supplemented and hence saved time. The robots' value as tools often motivated people to want

to get more robots or to give it as a gift to others. Now always, robot usage meant the time saving as people still got involved with emerging tasks such as robot maintenance that took as much time as the manual labor. However, participants expressed the joy and leisure-like feelings around the robot related activities, and did not mind the workload.

R.2 *An agent* that directly impacts the surrounding environment: robots induced physical impacts, such as removing pet hair on the floor, and moving smaller objects during the navigation. In the empirical studies, I found several householders to modified their homes (referred to as Roombarization) to better run the robot, such as cutting the rug fringe, moving furniture, and clearing up the wires [89]. It also affects household routines, such as closing all the doors before leaving for work during which a robot cleans, and checking on the status of the robot when coming home from work.

R.3 *A mediating factor* that motivates people to make changes in the environment: robots sometimes elicit negative impacts, such as breaking a mirror and dragging wires. The limited compatibility with the existing environment mediates people to make necessary changes to incorporate robots better.

R.4 *A mediator* that enhances social relationships among household members: in my study, I found that children and men took more responsibility in cleaning after robot adoption. Further, robots often became a new means for social activities. For instance, people demonstrated robots to the visitors, and even took them on their vacation to show around.

R.5 *An agent* that engages with people in social events: people ascribe lifelike qualities to a robot, and directly engage in social activities, such as giving names, genders, and personalities. Often, the ascription of life-like qualities trigger emotional responses (or vice versa), contributing to the feeling of meaningful

relationships. In other words, the perception as a social agent often led people to treat a robot more than a piece of machine, which I found positively acting to forming a long-term relationship because people tend to provide a better caretaking. However, not everyone exhibits this type of relationship.

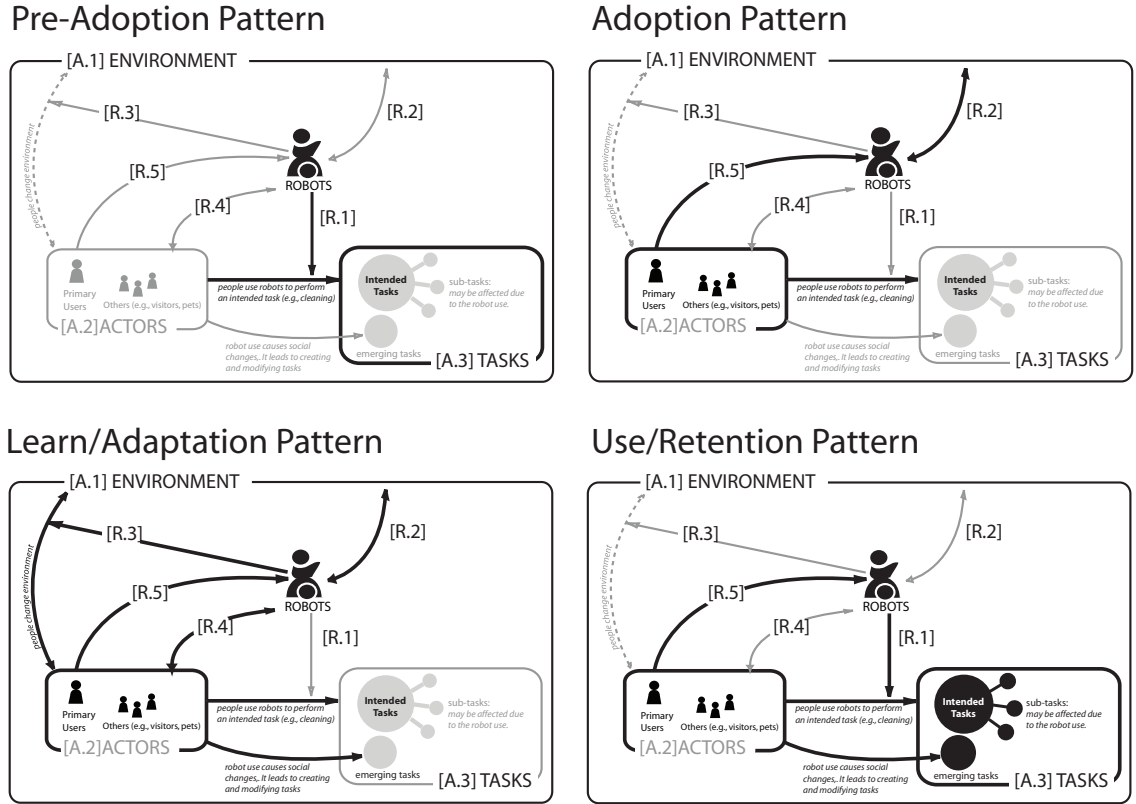


Figure 24: DRE displays the interaction pattern changes over a prolonged period of time (pre-adoption, adoption, learn/adaptation, and use/retention)

In addition to presenting the five highlighting relationships occurred between robots and the surroundings in the home, DRE shows how these relationships change over time (Figure 24). As Battarbee [5] points out, meaningful relationships between human and product do not suddenly occur but build over time. Norman adds to the time argument that different time may possess different meanings [64]. He divides the experience into visceral (first impression), behavioral (while in-use), and reflective (while not-in-use) stages. Researchers [51] try to unpack the long-term impact

on the perceived value of the product particularly in the way it becomes a part of the person’s identity. In the empirical studies, I also found that people form different meaningful relationships with a robot depending on how long they have interacted with it [82].

The division of interaction over a specific period of time reveals the interaction patterns that appear crucial to lead the user experience into a positive direction at that temporal stage. I highlighted the interaction that particularly influenced the user experience in bold lines per each time stage in Figure 24. Taking pre-adoption period for example, a robot’s capability to perform intended tasks and to work compatibly with the home environment largely motivated users to adopt it, and hence I marked those interactions in bolder lines. The interactions that impact the user experience differ depending on how long householders have used the robot, and hence highlighted differently at each time (see the bold black lines in pre-adoption, adoption, learn/adaptation, and use/retention). The visual depiction of the interaction patterns in each temporal stage show a clear contrast in the types of user experience people engage with robots over time.

DRE “Pre-adoption” View: Prior to adoption, people considered the robot as a utilitarian tool. They envisioned the robot experience to center around task performance (e.g., floor cleaning), such as how well it would work compatibly and durably with various types of physical spaces (e.g., floor types). And when these high expectations for compatibility and durability fall short, people lose their interest in further adopting robotic appliances. For design, it implicates the importance of envisioning and articulating a detailed list of obstacles that would limit the robotic appliances to operate autonomously and independently. Taking Roomba as an example, designers can suggest a large wheel as a potential requirement to prevent a robot from getting stuck in wires and clutters.

DRE “Adoption” View: When householders ran the robot for the first time, they

exhibited strong social responses toward the robot, and engaged in exploratory activities, such as running it outdoor and on a pool table. They began to perceive it more than a tool and something closer to a lifelike agent. The elicitation of social relationship between human and robots contributed to increasing emotional and entertainment value in the experience. It leaves several implications to interaction design. First, designers may implement expressive motions at the beginning to increase emotional and entertainment value. Second, designers can consider making robots to exhibit and comprehend social actions, such as being able to greet and wave. Third and finally, designers can enhance a safety system that can protect the robot from people’s random experiments, such as running it on a place with height. At the same time, robots should be able to inform participants through clear error feedback when people’s experiments caused technical problems.

DRE “Learn/Adaptation” View: After the initial adoption, people continued to spend time and effort to make necessary adaptations, such as changing furniture layout. Also, householders engaged with robots in various social activities, and began to ascribe a unique identity (e.g., names, gender, and personality) to them. Further, robots chanced social roles in the house. They induced collaborations among more householders to complete previously manual vacuuming task that used to belong to one person prior to robot use (e.g., Mom for cleaning). This finding suggests that even for a simple utilitarian robot, the ability to learn and adapt to social norms can become critical for long-term acceptance. Further robots need to identify household members and respond differently to offer personalized interactions, such as triggering companion-like relationships with children. The key design factor for a robot is to be able to learn and evolve according to the social needs in the household.

DRE: “Use/Retention” View: Over an extended period of time, Roomba had become a tool specialized in keeping the house clean. However, in order to accommodate error-free autonomous operation, householders implemented several strategies, such

as localizing and rotating the cleaning area. By default, robots should be able to map the entire house as localized cleaning routines could impose cognitive burden on users, particularly those that are young or technically naive. Further, they should allow users to select whether to run it in the entire house or a specific area of the home. In addition to operation strategies, participants put a particular emphasis on the maintenance by incorporating a whole new task in their domestic routines so that they could retain the use reliably. However, some participants easily forgot the time to clean the machine, which led to performance failure. To sustain a good quality performance, robots should be able to activate self-initiated notifications to users for timely operation and maintenance. Finally, the study participants tried to strategize other related tasks, such as carefully selecting the place to store home base. They sought a place that was less obtrusive to the eye but visible enough to get reminded of its presence and to continue the use. It indicates that robot exterior design should also be carefully crafted, and allow users to customize robots' look and feel to blend in or stand out in their domestic spaces.

Overall, I introduced DRE, a framework to articulate long-term interactions shaped by robots at home. More specifically, I presented two types of views within this framework. First, I showed a holistic view (Figure 23) to capture the overall interaction experiences that robots create across all temporal stages. Second, I showed the temporal view (Figure 24) that highlighted the key interaction patterns that respectively emerged over time. DRE supposedly augment the robot design process by: (a)helping define the attributes that play important roles in the robot interactions, (b)helping set the basic interaction scenario to complete a given task, and (c)helping map the developed interactions onto DRE, and create an interaction scenario, following the relationships described. It will help reveal weakness and strength of the design in an overall user experience. Some of the DRE discussions may appear vacuum centric, but the evaluation of DRE by applying it in the design of a senior-care robot (see

Chapter 5) shows that it can address broader design targets.

4.2.2 Step 2: Drawing detailed design instructions

Once the high-level experiences were elaborated, then the guidelines suggest that designers should make more detailed design decisions, such as how the robot should look, behave and communicate. My guidelines organize the extensive design agenda in three parts: interactions for robot operation (e.g., mechanical structure and form factor), interactions for robot communication (e.g., dialogues), and interactions for social and emotional engagement. These parts reflect the order of interactions related to low-level and mechanical operations, interactions related to controlling those operations, and finally interactions related to enriching the interactions—I explain how I draw these three dimensions in Chapter 4. Ultimately, this categorization is to allow designers to better structure the complex nature of the robot interactions. These three levels are not strictly divided levels; they are inter-connected. For example, one cannot design how a robot approaches a person without considering the surrounding social context. This division is an attempt to add structures to a seemingly broad and ad-hoc process of designing robot interactions.

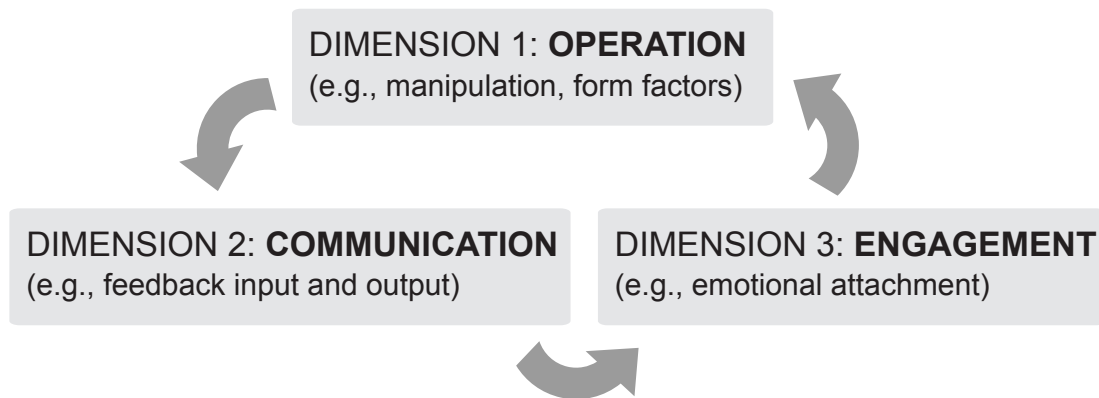


Figure 25: Three dimensions to organize robot design requirements)

I first present a summarized version of these detailed design instructions in Table 12, and then follow up by showing more explanations below.

Table 12: A summarized list of detailed design instructions

<p>OPERATION DIMENSION</p> <ol style="list-style-type: none">1. Plan paths for both global (entire house) and local (certain areas) operations.2. Change robot motions over time from being fun to being efficient in task performance.3. Plan motions sensitive to height and orientations.4. Balance visual compatibility and visibility .5. Reduce operation noise from robots, and hence allow multi-tasking from householders.6. Plan for a broad range of operating environments to allow smooth operations in all (floor) conditions.
<p>COMMUNICATION DIMENSION</p> <ol style="list-style-type: none">1. Allow both autonomous (let robots do tasks) and manual control (let me control robots go to the living room).2. Provide an interface that tracks and logs robot activity for troubleshooting.3. Modes of interaction/control: voice command most preferred. But think of controlling robots where voice cannot reach.4. Learn for personalized communication (e.g., recognize personal favorites, names, gender), and show this learning process.5. Consider safe and secure services to increase its utility and usefulness in everyday settings.
<p>ENGAGEMENT DIMENSION</p> <ol style="list-style-type: none">1. Provide long-term engagement. Make it less predictable and lifelike.2. Create personally meaningful relationships through customizations.3. Enhance entertainment and sociability and allow it become a companion-like being.

Operation dimension refers to the interactions for basic hardware configurations and mechanical manipulations. They comprise how an arm moves, how it navigates around the house, how it handles a threshold, and how it looks and fits into the environment. Specific guiding points for ‘*Operation Dimension*’ include:

1. *Plan paths for both global (entire house) and local (certain areas) operations:* householders use robots for both global operations (e.g., cleaning the entire house, and delivering an object between rooms) and local operations (e.g., grabbing a remote from the floor and handing it over to a persons hand). During global operation, robots need to move efficiently to complete tasks and to save

energy. During local operation, robots should move slower for fine and safe control.

2. *Change robot motions over time from being fun to being efficient in task performance*: Industrial robots are designed for efficiency and optimal production. Systematic movements is critical. However, robots for the home needs different strategies. If robots perform entertaining or simple utilitarian tasks that do not administer safety and risk related tasks (e.g., monitoring heart rate), robots are recommended to take expressive paths (e.g., circling around to get to a point). People feel systematic and optimal movements out of the box as machine-like. Over time though, they want robots to learn the navigating paths and act in an optimized way to serve the task efficiently.
3. *Design motions and forms sensitive to height and orientations*: people can sit, stand, lay down and do more. In whichever posture they take, they will expect robots to be at their eye-level in order to exchange feedback (particularly if it takes voice commands, shows information on screen, and delivers items). Also, for a robot that has a screen and provides info-tainment, people will try to interact with it even when it is stationed, such as being in the charger. That said, the charger and the screen cannot be on the same side; and the screen should always be facing the direction that people may approach from.
4. *Balance visual compatibility and visibility*: For everyday robots, it was not crucial whether or not it looked anthropomorphic. What played a more important role was how it appeared compatible with the rest of the house, yet visible enough so that they remember it exists. Three design alternatives can be considered. First, one can design the charging base to look as a piece of furniture, so when the robots are not in operation, they would be hidden. Or the robot itself can meta-morph into a piece of furniture. Second, one can design and

provide customization kit to allow householders to configure the form of the robot such as the skin to appear more compatible with the interior. Third and finally, one can increase a robot's cognitive visibility by utilizing its networking capability of the robot, so when it is not used for a certain period of time, it can trigger a email-or-SMS-based reminders to people for a run.

5. *Reduce operation noise from robots, and hence allow multi-tasking from householders:* Participants tend to use the robot in conjunction with other tasks in the home to save time. The operation noise from the robot often become the hurdle for the efficient use, which led to decreased use. However, a few participants use the noise as cues to identify accidents (e.g., noise stops = robot got stuck somewhere). Again, enabling robots to communicate with householders via network such as sending a rescue email when getting stuck can minimize the need to take cues from its noise.
6. *Consider a broad range of operating environments and plan for potential failure:* Our homes are places that comprise a number of objects including clutter on the floor. Robots will encounter hurdles in smooth operations. In the beginning, people will make certain changes to adopt robots such as cutting off the rug tassels. However, it will discourage them from using robots if those changes began to overwhelm their normal routines. During robot design, designers need to list all potential hurdles that may hinder robot operation, such as thick carpets, rug tassels, bottom of lamp stand, door threshold, small toys (robot chokes and stops working), electric cords and dog pads. One common solution is to adjust the wheel size to overcome these items. However, getting too big of wheels again creates problems including damaging expensive fine carpets, antique furniture and leaving visible tire marks on the carpet, which some householders responded negatively.

Second dimension concerns human-robot communication including how they give and receive feedback to each other. More specifically, this stage determines input and output modalities including, how people should initiate dialogues to robots (e.g., button press, speech recognition, and touch), or use an interface to remotely control the robot. The guiding points for ‘*Communication Dimension*’ include:

1. *Allow both autonomous (let robots do tasks) and manual control (let me control robots go to the living room):* In routine usage, people want robots to perform tasks autonomously via minimal to no interactions. However, In certain occasions, people want to remain in control of robots’ operation. Those incidences include scheduling an operation, customizing or localizing the operation path (e.g., go straight from entrance to the kitchen, or staying in the living room until battery runs out), and programming conditional operation (e.g., only vacuum if dirt detected). Also, they want to manually control if a robot performs any tasks that involve safety risks such as cutting vegetables or carrying heavy objects.
2. *Provide an interface that tracks and logs robot activity for troubleshooting:* Studies show that people will make certain changes to adopt robots such as cutting off the rug tassel. The challenge was that it was hard to identify spots that robots experience operation difficulties because robots autonomously move in spaces that do not necessarily involve human monitoring. Participants spend weeks to make the initial adjustments by following the robot around the house, and likely to continue this practice throughout the usage. It largely decreases the product satisfaction because they feel robots demand unnecessary inconvenience and create too much load. A robot needs to log its movements and record where it met challenges as a tool for easy maintenance. That way, people can go over the data and identify where and what to adjust in the environment.

3. *Allow multiple modes of interaction and control:* Most people selected voice commands as the default communication medium. However because the home is large, people need to control robots that operate in distance where voice cannot reach. That said, designers should consider how to interact with robots in various proximity either using voice or other remote medium, such as an application on a smartphone or an embedded feature in a TV remote control. Likewise, people wanted robots to communicate with them using various methods. Robots themselves could make visual remarks or auditory feedback to catch attention and convey messages. If the messages are related to maintenance, people prefer to receive in a written manner, such as showing what is required on a LCD panel. If robots operate in distance but need to send a message, people desire a smart messaging system, such as robot send the message to nearest TV or a monitor where the person stays or to mobile devices. That way robots can continue working on a task, and save time to take a trip to just send a short message. In sum, people desired ubiquitous means to give and receive feedback to and from robots in the home.
4. *Should learn and show its learning process:* Robots should be able to learn to adapt to the environment and household routines. Also, it should be able to learn different household members and recognize their preferences and needs (e.g., delivering the right type of medicine for each household member). Further, the study shows that robots should not only learn but also should clearly demonstrate its learning process. Householders expect robots to show progressive development from being new to the environment to being familiar to the space. They want to see the learning in the way robot acts more efficiently (e.g., completing a task quicker) and intelligently (e.g., remembering a person's name). The study shows that householders rapidly lost the credibility in robots' performance and intelligence when they see the robots make the same errors

repeatedly.

5. *Consider Safe and secure services*: robots movements should be pet and children safe. Also, for robots that handle personal information over network (e.g., managing schedules, reading emails and connecting video-conferencing system) need to protect from getting hacked. In addition to the personal information, robots can recognize and sense a lot of household routines. For example, robots can record your activities through embedded camera and store the information inside. The information should be safe from intrusion, and should allow customizing what robots can or cannot record. For designers it is important to draw up all possible scenarios for safety and security risks factors, and ensure that robots can provide advanced services without risking domestic lives.

Third dimension concerns engagement; it takes more than functionality and aesthetics for robots to become accepted in the home. Robots need to elicit meaningful relationships with householders. Below are some of the suggestions identified from the field studies that designers can consider for making robots appealing socially and emotionally.

1. *Provide long-term engagement. Make it less predictable*: Householders become bored with a robot when they could see predictable patterns and start decreasing the usage frequency which in cases led to discontinued adoption. With Roomba, users enjoyed the random movements; they reported them expressive and unpredictable just like human-beings. They discussed that the unpredictability in robots' movements was the key for them to continue to interact with it over a period of time because it was fun and stimulating. Also, they explained that unpredictable actions are unique to lifelike beings (not machines), which made them perceive robots as social agents and deepen the engagement. Over time, as the robot shows the same random movements, they begin to describe it

boring and stupid. They wanted to see new types of movements and response patterns. In general, people wanted robots to learn new things and become constantly stimulating to observe. However, I do not argue that all robots should begin with random and emotive behaviors. Some tasks such as health monitoring for senior people need to be carried out with precision. Also, too much randomness might confuse people as it may appear broken.

2. *Create personally meaningful relationships through customizations:* Household-ers customize robots by changing the skins or writing down names on the external case. They note the customization activities help connect them deeper with robots as not just a mass-produced artifact but something personally meaningful to them. The study shows that personal attachment positively influences people to carefully maintain the robot for long-term use. One common way to customize robot was to give it an identity. Most notably, they named the robot, referred to it in a gendered way, ascribed personalities, and even personalized the look using stickers, skins, and knitting. It implicates that designers should consider providing means to personalize robots, such as making the external surface configurable, or enabling people to construct a robot's identity through giving it a name, a gender and a personality. The personalization should be reversible as householders continuously negotiate on robots' identity (changing robot names) and the external surface.
3. *Enhance entertainment and sociability:* People are going to engage with robots in an entertaining manner whether or not the robot is designed to provide it. In my study, householders created a race track to compete with neighbor's robot, ran it on the pool table, delivered a gift by remotely controlling a robot and more. Through these activities they felt robots brought new social dynamics in the home, and started accepting it more as a necessary part of the household.

Also, robots will be used by a various types of social actors in the home including children and pets. Their active engagement with robots created another set of new social dynamics and hence increased the fun of using it. In particular, children played with vacuuming robots while actually cleaning the house, which they perceived as a drudgery before. Designers could think of ways to enhance robot’s entertainment by utilizing sociability, such as initiating games with children or inviting pets to play together.

4.3 *Summary*

In this chapter, I introduced my participation in a real-robot development, called as HomeMate project, and described how this experienced helped frame the initial set of the design guidelines. The participation in HomeMate design process shed lights on two large implications to frame the lived experiences with robots. First, the guidelines need to provide a tool for designer and developers to re-construct the lived experiences to mediate the absence of their own due to the novelty of this product. Second, the guidelines need to be organized in the way a) designers can quickly draw the information necessary to them and b) developers can learn about how to implement social and emotional interactions in the design. Thus, the guidelines focus on two things: constructing holistic robot-experiences in the home using DRE, and drawing out detailed design requirements related to operation, communication and engagement. I stress that these guidelines differ from the robot design implications introduced in Section 2.3.3; my guidelines contain design consideration for long-term adoption patterns. In addition to these implications, HomeMate experience offers implications on the design process that the guidelines need to be introduced at the very beginning of the process to get accepted by both designers and developers without, and it should be a means to encourage for them to generate design concepts together.

Next, I assess if these guidelines make sense in the robot design process. I simulate

the early design development process of senior-care robots (like HomeMate), and invite designers and robot developers to create concepts with and without guidelines to evaluate the usefulness and potential areas for improvements.

CHAPTER V

EVALUATING DESIGN GUIDELINES

In this chapter, I present the results from design experiments that I undertook to assess the practicality and usefulness of the proposed design guidelines. I invited product designers and robot engineers to generate design ideas for robots similar to HomeMate. I gave guidelines to half of the groups and compared and contrasted the results with those that did without guidelines. The results show that those with guidelines were more productive in terms of the number of ideas that they generated and the depth they went into developing concepts. They found the DRE particularly helpful as a way to familiarize them with robotic experiences in the home and to focus their thoughts on users. However, I learned that the groups without guidelines often produced creative and interesting ideas as they were not constrained by any guidelines. The study shows that the use of guidelines proved to be useful for designers and developers who were new to this process. However, since the use of guidelines could compromise the creative outlets, the initial design process might begin with free ideation and then build more concrete concepts with guidelines.

5.1 Study Methods and Participants

I conducted design workshops with design practitioners and roboticists to learn creative insights for future senior-care robot (Figure 26). In total, I held 10 design workshops. I recruited two designers and one roboticist for each session (in the rest of this paper I will refer to all the participants as designers, reflecting their participation in the design process), and asked them to work together for three hours to generate a design concept for a domestic elder-care robot. The study was conducted at the Aware Home of Georgia Institute of Technology, a real house modified for research

focused on developing future domestic technologies (www.awarehome.gatech.edu). I selected this site to help study participants envision robot use in the home.



Figure 26: Design workshop view

5.1.1 Study procedure

The design workshop consisted of three steps. In the first step, I introduced the purpose of this study: to get designs for a consumer robot that supports elder-care. I asked them to envision a robot to be deployed in market in 10 years time in order to maximize each team’s creativity by releasing them from being overly constrained by the current state of technology.

In the second step, I provided each team a persona (Figure 27) and a storyboard of seniors’ needs for robotic assistance (Figure 28) that I generated based on the related literature [2, 31, 43, 54, 68, 94]. The personas and storyboards illustrated the daily challenges seniors experience such as organizing medication [68], coping with limited mobility [31, 43], communication constraints [94] and more. These research-grounded user data provided a consistent frame of reference across people with different backgrounds, and hence increased the efficiency of the teams in the three hours. Also, the same tasks allow for easier comparison of the design outcomes across teams. Along with persona and needs analysis, I gave design guidelines presented in Chapter 4 to five of the teams. I only gave it to five teams to compare and contrast the impact of guidelines with the other five teams that designed without any guiding points. I sent the long guidelines (see appendix) about four days before the scheduled study so that

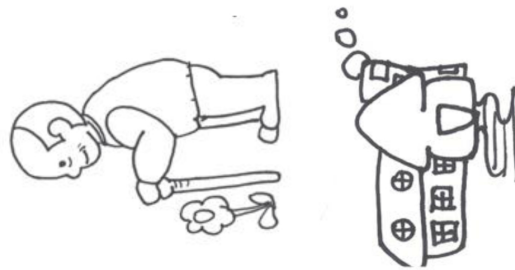


Figure 27: Persona used for robot design sessions

Name: Scott Thompson (76)

Life style: Scott is a retired math teacher. He lives alone in a four bedroom house (3000 sq ft). His daughter, Tasha, lives close by and visits frequently. She is the primary care provider for Scott. If she cannot visit, then she calls daily to check his well-being. She often brings her children, Sean and Lia because she knows that seeing grandchildren cheers him up.

Scott tries to lead an active life. He regularly hosts a tea party in his house with his neighbors, and enjoys going to the church and the nearby park. He fears that he would not be able to live such a life as his health degrades each year. Plus, living alone in a big house makes him feel lonely at times. He once considered going into an assistive facility where he can meet people and be well taken care of. Also, he feels that it becomes more burdening for his daughters to take care of him. But he would really prefer not to leave his home where he lived with his late-wife for more than 35 years. Luby, a shepherd dog that he stayed with for seven years is another reason that he would like to stay at home.

Health: He begins to realize that his physical strength and dexterity deteriorate each year. He takes a walk at least once a day as an exercise although these days he wonders what he could do more to stay fit. His hearing and eye sights are another sign of aging. He has to wear hearing device in his left ear all the time, and now he wears two types of glasses: one for reading, and the other for general seeing. The number of medications he has to take increases, too. He takes daily medication for his heart and high blood pressure. The bigger concern is the memory loss because he often forgets to take medicine on time. It is in fact the biggest concern that Tasha has for her father.

Technical sufficiency: Scott does daily computer use such as an email and basic web-browsing. Even that, he feels complicated and difficult. Recently, Scott learned how to use Fax machine to communicate better with Jenny, another daughter who lives oversea due to the increasing challenge in communication through phones (hearing problem). He recalls how resistant he was prior to adopting it. Also, his daughters got him a cell phone over the Christmas for emergency contact, which Scott complains about the small keypads. They initially bought him an emergency necklace but Scott refused to wear it because he did not want to appear disabled and fragile by wearing an aid device.

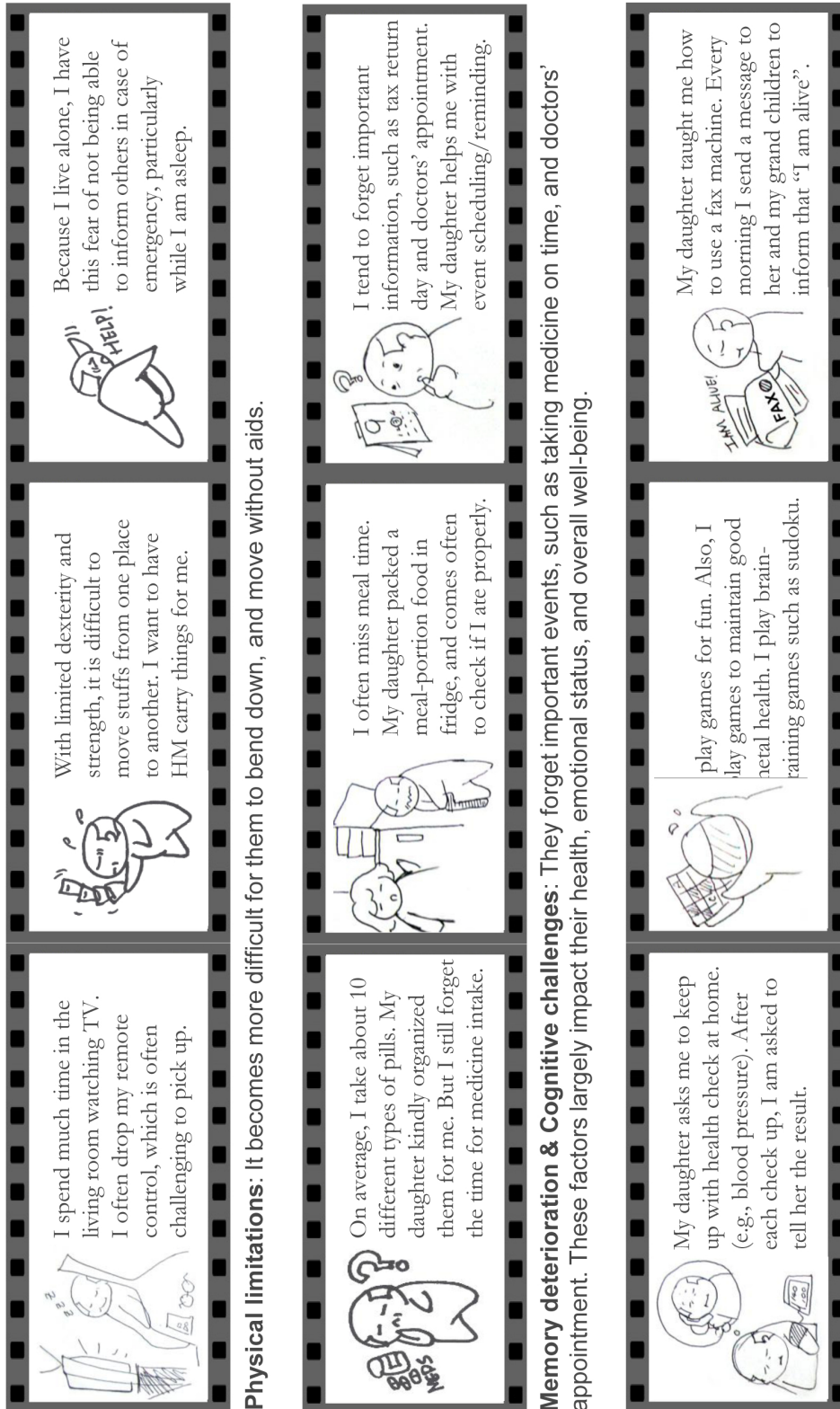


Figure 28: User needs storyboards: HM stands for HomeMate

participants would have enough time to digest the content. To ensure that they read the guidelines, I asked them to send me a summary of the guidelines and five points that they thought were interesting. During the actual design workshop, I gave them an one-page version to remind the memory and to refer back to guidelines easily (see appendix).

In the third and final step, participants designed robots according to their own process. I did not specify how they should design, but did request three deliverable items at the end: something that explained their visual ideation process, design rationale that logically explained how their robot looked, moved and interacted with elders, and one final concept that the team has agreed upon. During the design process, the researchers observed but from a distance and did not talk to them in order not to influence the process with our pre-conceived notion of senior-care robots.

I completed the study by asking them to present their design ideas and gathered their reflections on the study procedure. I audio and video-recorded the entire design process for each workshop session.

In addition to these steps directly related to robot design, I asked study participants to give feedback on the robot design in general and on the guidelines if applicable. To learn their thoughts on the robot design, I used conceptual mapping technique by asking them to rate some robot design attributes: usable system, reliable operation, look and feel, affective interactions, social adaptation and technical advancement—see Figure 29. I asked them to do this before and after the study so that I could compare and contrast how the design sessions or the use of guidelines have influenced their existing view on consumer robot development. Further, I gave them a set of ratings after the design sessions including the perceived easiness in the process, the perceived difficulty and easiness compared with the design of other technical products, and finally the need for guidelines if they are available. For those groups with guidelines, I asked additional rating questions related to the

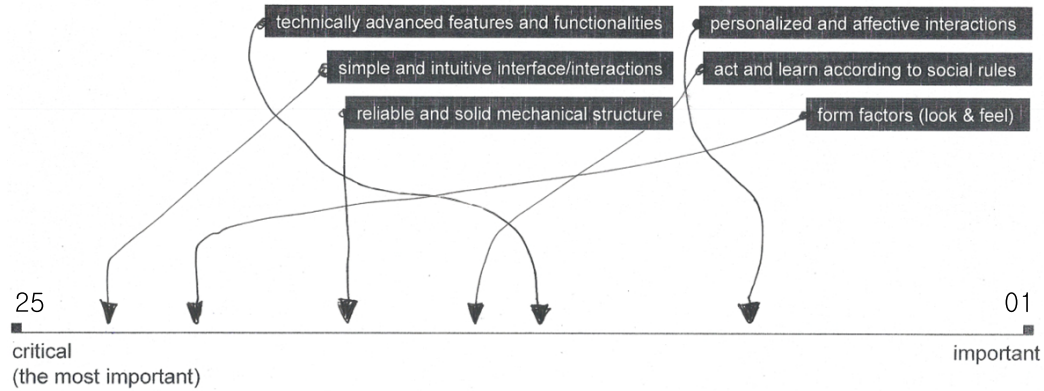


Figure 29: Conceptual mapping to learn what designers and roboticists think important for robot design

current guidelines, such as the effectiveness, informativeness and comprehensiveness (e.g., content organization, length and clarity).

5.1.2 Study participants

Across the ten design workshops, I recruited 30 participants (16 women, 14 men: mean age=27). Among them, I had 20 designers (18 product designers and 2 interaction designers) and 10 roboticists through word of mouth, and personal mailing lists. I pre-screened all participants to have appropriate expert knowledge; I required designers to have more than three years of professional or academic training with at least one project or a class related to product design; I defined robot experts as someone with at least an undergraduate degree in an engineering related field and currently participate in a robot-related project. None of the 30 participants had experience of designing a consumer robot. The 20 designers included students, a professor, product designers, and an interaction designer with a wide range of design experiences from 3 years to 28 years (mean=6 years). On average, they were 27 years old and consisted of 15 women and 5 men. Only one of them had experience with robots in a project creating a kinetic art installation. The 10 roboticists had worked in robot-related projects (including robot control system, healthcare robotics, and factory robots) for 5 years on average, ranging from 2 years to 10 years. All ten roboticists reported

having familiarity with robot software while five of them also had experiences in constructing robot hardware.

The design workshops generated various types of data; each group produced a set of sketches, diagrams and written notes used for brainstorming, and refined drawings for the final concept. Three groups even created user scenarios to depict how their proposed robot could be integrated into an elder's life. In addition to these participant-generated materials, I transcribed video-recordings to capture the design process with detail. In total, I have 484 pages (137431 words) of transcriptions that include time markers, action markers (e.g., quietly sketching for five minutes), and made notes of conversations (e.g., who talked about what). Many of the discussions centered on the visual sketches, and hence I scanned the design materials from each session and cross-referenced them with the conversation. I analyzed the collected data and learned how guidelines were used and if they had any impact in the design outcome. I analyzed the design sessions in three ways: (1) assessing design outcomes, (2) capturing the work process such as how the members collaborated, communicated and assigned the tasks, and (3) comparing between the teams with and without guidelines. Two researchers coded the transcripts to learn these three points.

First, I scrutinized the data to identify the design choices from each team's process. Again, two researchers (including myself) coded transcripts based on the six design criteria: form factor, intelligence, operation, sociability, interactivity, and environment—that I explained in the related work section (Section 2.3.3). Two researchers (myself and a Master's student) independently coded the transcripts (the inter-reliability assessed using Cohen's Kappa showed an outstanding agreement level ($\kappa=0.834$, $p<0.001$)). The analysis reveals that designers and roboticists in the design workshop focused on form factor, sociability, and interactivity (28%, 28%, and 24% of the codes respectively). They spent less time focused on operations, intelligence and environmental considerations, such as how to make robots go up stairs,

and operate at night without sufficient lighting for vision systems. The codes from these three categories comprised 20%. All participants agreed to spend their time brainstorming a creative, usable robot rather than focusing on specific technical requirements that would likely change 10 years out. Also, designers preferred not to discuss engineering details in the beginning in order to have freedom to creatively approach the problem at hand and to prioritize user-centered solutions, all of which consequently left shorter time for technical discussions.

Second, I assessed the design process by marking team activities (e.g., brainstorming, discussion, sketching and more), following individual roles (e.g., who led the discussion, took notes and made sketches) and noting individual contribution such as frequency of discussion or attempts for new ideas. The analysis of these complex group dynamics were visualized for easier comprehension and comparison with other teams (see Figure 30 as an example).

Third and last, I used these two data (design outcome and process) to compare and contrast the groups with and without guidelines. I sought to learn utility (if participants could use the provided information), practicality (if guidelines actually helped the process) and potential improvements. To compensate my personal bias in the comparison, I discussed and drove comparison and contrasts with another researcher who was involved in the first and the second step of the analysis.

5.1.3 Study limitations

Simulating a real-world robot design is a difficult task; robot design is an expensive process that is high in costs and demands a number of experts in various fields (as described in Chapter 4). In the scope of this thesis, I present a study that tries to resemble the situation for the early senior-care robot development, largely inspired by the HomeMate process. But this study has limitations; here I note them that could have influenced the study outcome. These are the points that need to be considered

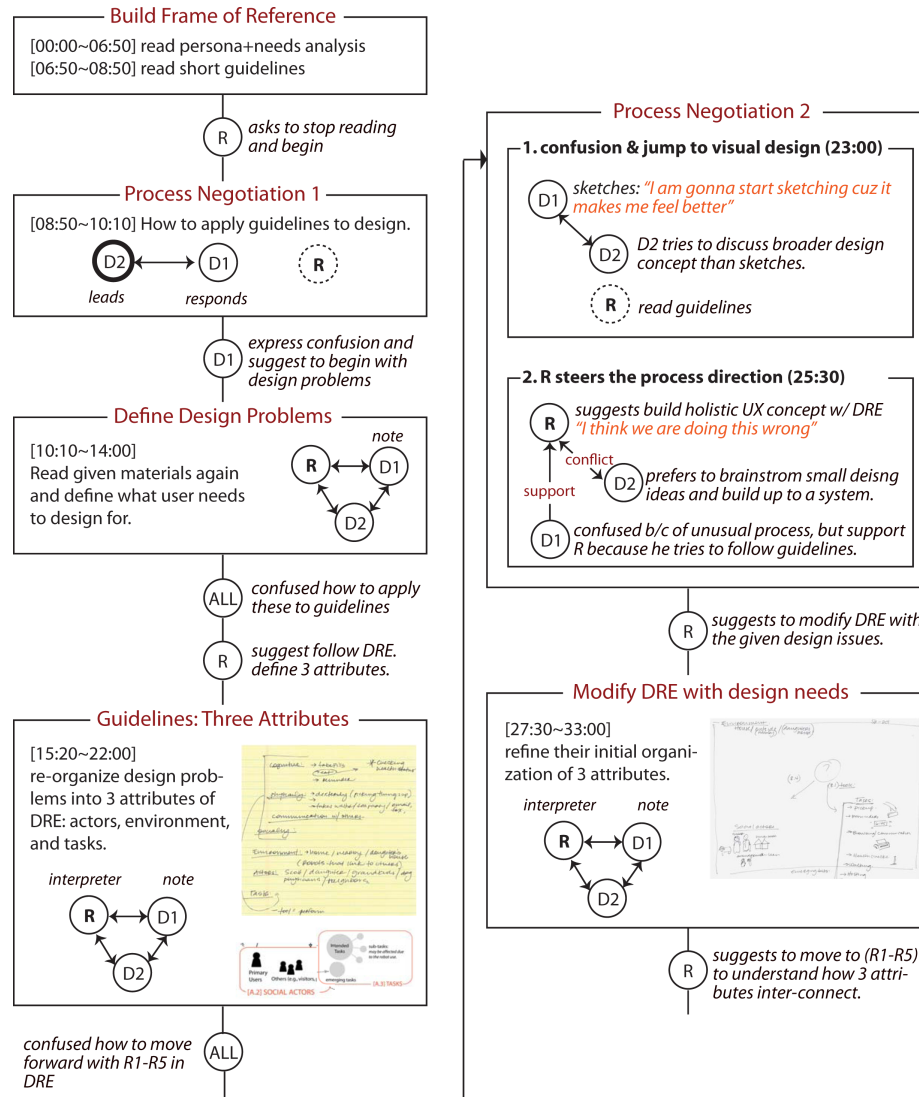


Figure 30: Work-flow diagram of Team 08: R-roboticist, D1-designer01, D2-designer02

and addressed if there will be more design guideline assessments.

First, the recruited participants did not always have the level of expertise of the designers and robot engineers involved in the HomeMate project. They were largely from Georgia Tech who were still students. I tried to recruit design and robot experts with years of professional experiences. However, it was difficult to do with the resource available in school.

Second, the study assessed group dynamics among the people who never worked

together before. I intentionally chose random group assignment because in HomeMate projects, the designers and engineers from different firms have not worked together before this project. One goal in this guideline assessment was to see if people who have not worked together could collaborate better if the right tool were given because I saw how other robot design could draw people from multiple firms. However, another design process might also take place in one company that develops the entire robot from the hardware platform to the cosmetic forms, which would involve teams who have worked together for an extended time. This particular study does not confirm the guideline impact and use in those settings.

Third and last, this study only compares and contrasts two groups: one with robot design guidelines and the other without guidelines. One possible explanation for different outcomes between these two groups is the existence of a tool itself; the groups with an instruction might simply work better than those without an instruction at all. To better assess the impact of the content of the guidelines, I suggest a future study with more groups, such as those that are given existing design guidelines established in Human-Computer Interaction and other product design areas (e.g., chair). Also, a further study may compare the groups with the proposed guidelines in this thesis with the high-level robot design criteria presented in the related work (Figure 3 in page 23).

Next, I present these results. I begin by describing the robots created from the session to show that the study has produced solid design ideas despite the short amount of time allocated to designers. Then, I explain how the sessions with and without guidelines differed in their outcomes, and further present how the guidelines were used in the session. Finally, I discuss the lessons from these studies, and reflect on potential improvements.







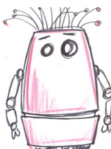



5.2 *Design Results*

The design workshops resulted in 10 elderly-care robots. The designs included a spectrum of ideas including a humanoid robot that looked like a super hero from team five (abbreviated as T5 throughout the paper), a personal robot that resembled small furniture from T10, and a hovercraft inspired concept from T8. I summarize these design ideas from all teams in Table 13.

To explain these concepts with detail, designers approached the form factor with a keyword: familiarity. To some groups it meant lifelike qualities such as pets and little children, and to others it meant nostalgic appearances, such as a piece of antique wooden furniture. Above all, they put a great emphasis on comfortable look and feel because they thought the senior-care robots would stay with elders in close proximity all the time. The designers also portrayed robotic politeness through the size. Previous studies report that people perceive politeness and obedience from smaller robots, which they preferred more to bigger ones [56, 83]. This study shows that the default size of the robot was related to its proximity to the person. The closer the robots remained to the senior the smaller they were. Most designers' default robot height was similar to a coffee table, to comfortably fetching robot delivered objects or view information in their seated position (Figure 31). Six groups (T1,T2,T4,T5,T6,T7) designed their robot with a telescopic body to provide the same functions when the senior was standing.

In the participants' overall efforts to ensure user-friendliness in design, I saw the different approaches to these outcomes between the teams with and without guidelines. The differences are visible in the design outcomes (Figure 32). The groups with guidelines produced robots that resemble lifelike forms (i.e., head and body division) with a screen as the primary interaction point. In contrast, the groups without guidelines drew robots that varied in concepts. Other than the immediate differences in the

Table 13: Non-cleaning activities engaged with Roomba

Final Design	Robot Description	Final Design	Robot Description
	Team 1 (T1-without guidelines):pet analogy for form, customizable skin (soft silicon material for human touch)		Team 2 (T2-with guidelines):named as Tommy Boy, telescopic body to adjust height
	Team 3 (T3-with guidelines):named as Butler Bot, furniture look with curved body to show politeness		Team 4 (T4-without guidelines):transform into a sculpture look when inactive, telescopic body to adjust height
	Team 5 (T5-with guidelines):named as EL.E, super hero look with soft bubbly body		Team 6 (T6-with guidelines):named as BEAR!, a pet-like robot with storage for frequently used items
	Team 7 (T7-without guidelines):an emotional robot of which skin color changes to express emotion, hair flow changes to inform weather		Team 8 (T8-with guidelines):a hovercraft robot that flies close by for cognitive support, has smiley face as default
	Team 9 (T9-without guidelines):named as TABL (Task And Basic Living) that has furniture look and has stair-climbing legs		Team 10 (T10-without guidelines):a two-unit system: a large manual labor robot (Strong-bot), and a small social robot (Mini-bot)

final design, I identified different approaches led by presence or absence of guidelines in the way the participants achieved a)familiar look and feel, b)interaction modes, and c)sociability.

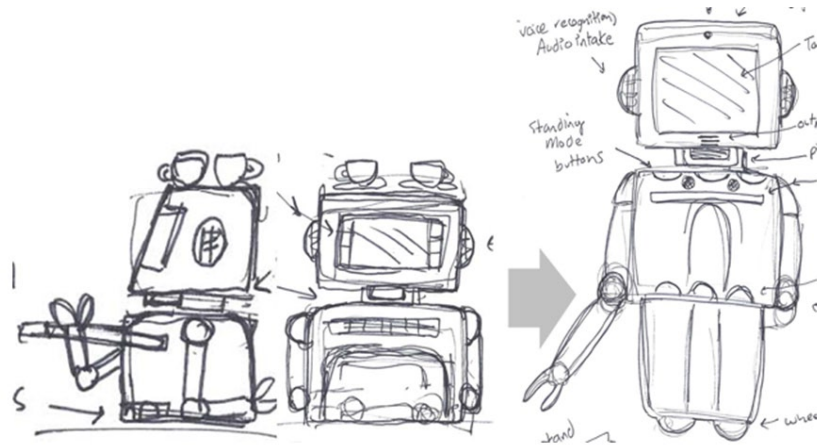


Figure 31: T2's telescopic body: coffee-table height by default

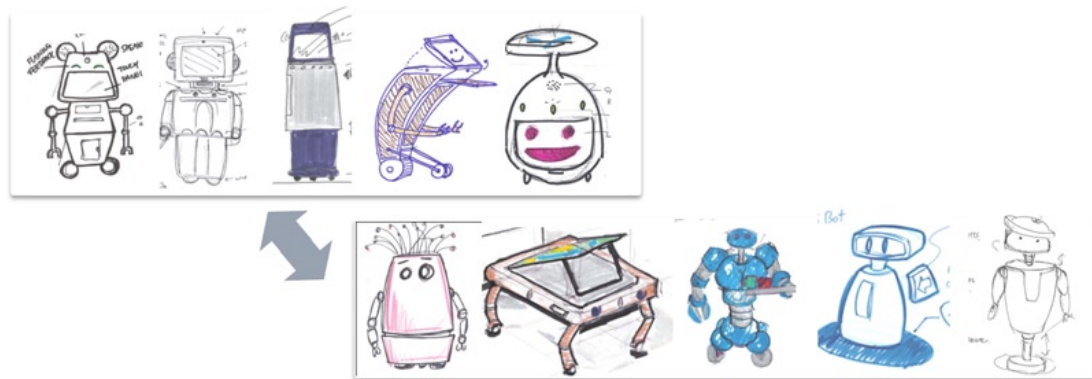


Figure 32: the design outcomes from the groups with guidelines (top) vs. without guidelines (bottom)

5.2.1 Familiar look and feel

Groups with and without guidelines varied in the way they tried to achieve familiarity. The groups without guidelines shaped forms to what elders might be used to, such as children, pets or a side table. Groups with guidelines took a step further; the designers and robot engineers utilized the information that Roomba was not adopted when it stood out in the environment (i.e., *Balance visual compatibility and visibility*), three groups (T2,T4,T6,T8) chose to hide manipulation when inactive because they felt the big metallic arms would intimidate elders. They suggested retractable or foldable arms that would look as a part of the torso and only come visible when

active. Only one group that did not use guidelines took a similar approach; T9 talked about making a small, companion social unit and a separate working unit that included manipulation (left in Figure 34). Their large unit (named strong-bot) did the heavy manual tasks but stayed largely out of sight being controlled by the social unit (named mini-bot) that stayed close to the elderly person. To increase mini-bot's friendly appearance, designers decided that it would not have a screen; instead it would work with other screens in the environment (e.g., TV screens) when it needed to display information.

I informed the HomeMate designers of the results that came out from the design sessions. And they sincerely took the design idea on achieving familiar look to become better incorporated in the environment. One of their primary concerns was to position the single robot arm; putting it in front made it look like an elephant, and putting it to the side made it appear crippled. Then, I emphasized the design guidelines that the robot form needs to appear compatible with the home interior, and showed the concept sketches of robot arms that retract when not in operation to make the robot as an information center (left:Figure 33). Inspired by the concept sketches, HomeMate designers made the arm to fold and rotate to the backside. So from the front side, the arm (the most mechanical part) remains visibly hidden when it is not in operation (right:Figure 33).

In addition to pursuing familiarity in the look and feel, designers sought politeness and subservience from the form in order to decrease adoption barriers. T6 made the robot bend 90 degrees when delivering artifacts (the back of the robot is an indented tray), and described this bending as portraying polite bowing (right in Figure 34). T3 made the body curved by default so it would appear to bow all the time. Further this team emphasized material choices as an alternative to increase familiarity; they decorated their robot with wooden panels that they thought would elicit nostalgic and friendly feelings from elders.

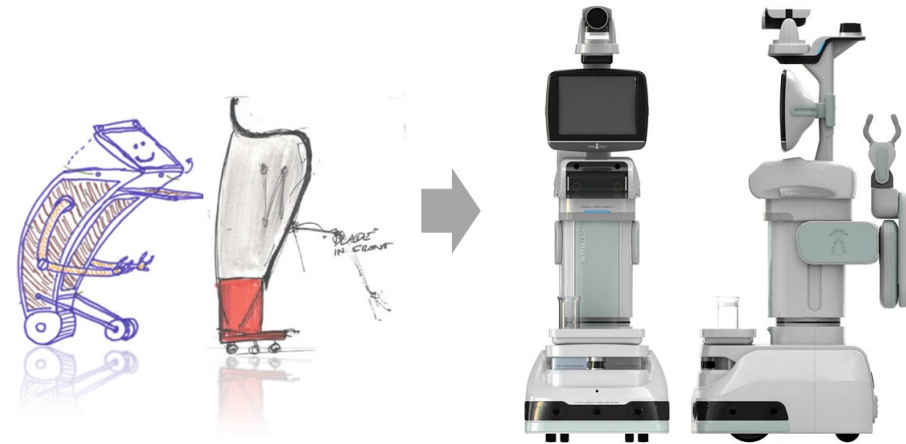


Figure 33: The robot design that tries to achieve compatible look and feel with the environment influences the actual HomeMate design; the arm of HomeMate now folds and goes to the back to become less visible and hidden when not in operation.



Figure 34: (left) T9's division of manual robot (strong-bot) and social robot (mini-bot) to give less mechanical look and feel, (middle) T3's polite looking robot with curved body that implies greeting, and (right) T6's bowing robot to implicate subservience through its behavior.

5.2.2 Interaction modes

Designers prioritized simple intuitive input and output, balancing that with their desire to support a wide range of cognitive and physical limitations. It naturally led them to devise multiple ways to perform the same action; for example, T8's hover craft robot had three ways to provide commands: voice, manual remote control, and a touch screen on the robot. All groups considered voice commands as the primary medium for input. They preferred voice because it did not require elders to learn how to interact with the robot via what they perceived to be a more complex interface

control.

Still, I identified different ways the groups with and without guidelines discussed the general interaction modalities. The teams with guidelines referred back to the need to control robots at a distance based on the guidelines: *Plan paths for both global (entire house) and local (certain areas) operations* and *Allow multiple modes of interaction and control*. While designers talked about voice commands as the primary method of communication, they saw audio having proximity constraints; robots could not hear the voice commands at a distance. Considering that assistive devices often get rejected due to the stigma they create [11], our designers tried to make these remote devices blend in to existing worn items including a watch, a bracelet, a hearing aid, a TV remote and a phone so commands could be issued via these devices. There are two important features on this remote device. One is an emergency button that allowed the senior to call for the robot when assistance was required, and also to force a shut-down of the system in case of malfunction. The other feature includes assisting elders when they are outside the home (i.e., church, park). DRE's suggestion to define environmental boundary encouraged designers to talk about how their robot's scope of assistance should naturally extend to the outdoors, such as providing navigation and weather information while on the road. Teams without guidelines also considered robot application in outdoor space but to the extent that it followed person to lift heavy objects to nearby grocery stores, which were often objected to by the roboticists; they suggested potential difficulties in designing mobility and way-finding systems for the open and unanticipated nature of the outdoor environment. T9 was the only team without guidelines who discussed remotely controlling and communicating with the robot through a smartphone-like device both inside and outside the home.

Thus, the groups with guidelines provided interaction ideas that could support elders in broader daily contexts. However, I also learned that the groups without

guidelines could provide more creative ways to interact with robots. For example, I noticed that many of the design groups struggled with the tension between providing feedback that gained the attention of the user while balancing that with having feedback not appear disruptive in the environment. The teams with guidelines discussed to resolve this dilemma within the input and output modes provided in the guidelines, such as lights, sounds, gestures and text-based information displays. However, some of those without guidelines were more outside the box; two groups (T1, T7) decided to use their robot's body color or decorations to explicitly yet subtly transmit certain types of information. T1's robot skin was designed to change virtual clothes projected on the body suggestive of current tasks, such as wearing tuxedo when hosting guests, and aprons when vacuuming around the house. T7's robot used digitized skins that changed body color to suggest the time of the day (e.g., blue in the morning, yellow around midday, and orange in the evening), which they told us would act as an ambient reminder for elders to take pills. This robot even had hair that waved smoothly to communicate the current weather conditions (Figure 6) that can also add fun to looking at the robot (Figure 35). Another creative interaction was to have robots communicate with existing domestic technologies that have larger screens such as the TV. This way, robots could still serve tasks related to information retrieving (e.g., reading email and tele-conferencing with grandchildren) without constraining design choices by having to implement a screen in the body. As shown in Figure 34, none of the teams without guidelines implemented 10"-14" display as the facial part of the robot.

5.2.3 Sociability

All study participants spent a lot of time discussing ways to increase sociability of robots, i.e. personality and behavior. They were all concerned that autonomy and intelligence might convey the impression that the robot was trying to dominate the



Figure 35: T7’s robot displays ambient information by changing body colors and moving body parts

elder’s lifestyle, forcing a lifestyle that is robot-centered, which have been reported as a potential cause that may lead to technology rejection among seniors [43, 31]. For example, seven groups (T1,T2,T3,T6,T7,T9,T10) decided to deliver the medicine in front of the senior but not to directly hand it over. They selected this method because it appeared more encouraging and appealing yet less demanding and aggressive. As a designer in T1 notes: “I think (pill dispensing) is better because otherwise it’s kinda treating him like he’s at a mental institute like hands you medicine and it has to watch you take it”. Our participants saw designing for social robots could prevent elders from feeling being dominated by robot-centric lifestyle. Yet, I noticed a different approach taken by the teams with and without guidelines to accomplish this increased sociability.

The teams with guidelines envisioned the robot as a fitting in with broader social dynamics surrounding seniors’ lives. One notable example was the focus of placing robots in the existing social structure, such as discussing how it should interact with various types of stakeholders, such as seniors, caregivers, pets and visitors. In particular, designers discussed at length how robots should augment the relationships between seniors and caregivers who take a significant percentage of many seniors’ social interaction who frequently call or visit [58]. They utilized robots’ sensing and networking capabilities for autonomous data gathering and sharing, such as, having

robots automatically collect heart rate and blood pressure and send the information to caregivers via text messages or a private website. They expected it to increase the feelings of staying connected between elders and caregivers while decreasing perceived burden for having to call frequently to touchbase. A designer in T2 describes this aspect with relation to medicine management: “for pill dispensing(robot) could measure the weight of the pills, the containers it gives to him, and tell the difference in weight (before and after the intake) so it knows whether or not he took them. And just record it so the daughter doesn’t worry. Robots can take over the less enjoyable parts of the communication for this family”. Designers saw these caregivers playing a crucial role in robot usage and maintenance, imagining them scheduling the time for a medication alert and helping the elder update phone numbers on the robot. They thought that the benefit caregivers would receive from the robot would make up for the burden of maintaining it. Also, the designers included pets and grandchildren as entities that would interact with the robot, in which case they talked about making robots small yet stimulating enough to feel intimate. At the same time, these stakeholders posed design challenges; dogs may bite smaller robots, which led to suggesting durable exterior skins; children may explore robots out of curiosity potentially triggering accidents. Designing for these stakeholders focused our teams’ attention on the balance between intimacy and safety. The groups also raised the possibility that robots could create opportunities to make new social acquaintances. They envisioned the robot identifying other units nearby using a GPS capability, and talked about having the robot encourage elders to contact other owners in order to build a user community. The participants that used design guidelines said that this focus on broader social interaction was primarily motivated by DRE’s suggestion to list all stakeholders in the home, and to consider how robots play a role to mediate and augment these existing relationships.

The teams without guidelines discussed robot sociability in a narrower scope; experiences that occurred directly between seniors and robots. Their focus was not to make seniors feel demeaned by receiving endless support from the robot. At the same time, they did not want to compromise robots' capability to assist elders. As a resolution, they utilized robots' personality to stimulate caring from the elders inspired by the pet-owner relationships. For example, the robots from T1 and T7 occasionally ask elders to take them to the charging base by saying "I am hungry. I need more power juice!" even though at most times it can return to the charging autonomously. T9's robot watches TV with the elders and asks for intellectual instruction by inquiring about what was displayed on the screen. In an essence, robots intentionally asked for help to sustain its physical and cognitive capability, affirming elders' ownership and control of these assistive agents. Designers noted that this personality will help decrease the perceived negativity associated with robot's constant caring without having to compromise robots' ability.

5.3 Design Process: Guidelines vs. No Guidelines

The result of the design workshop shows that the use of guidelines during the process clearly brings differences. Those with guidelines tended to produce more well-rounded concepts, balancing technical feasibility against broader and holistic social interactions including multiple stakeholder and various types of environmental constraints. Participants used both DRE and the three-step-detailed design insights (i.e., operation, interaction and engagement dimension) in what typically appeared as a four-step-process.

In the first step—after having read the persona and user needs analysis, designers and robot engineers turned those information to robot-specific design requirements; they listed what would go under the three attributes—environment, social actors, and tasks—as shown in step 1 in Figure 36. Then as the second step, they utilized

the five relationships in DRE to create a storyline of how a robot would interact with these listed variables. That is, they fully captured the robot experiences in a senior’s life prior to generating any concrete drawings as shown in step 2 in Figure 36. The third step is the construction and visualization of an actual robot as shown in step 3 in Figure 36. During this process, I saw two patterns. Some groups followed the three dimensions by constructing the design from operation to interaction and to engagement; others created the robot on their own, and then used the three dimensions and detailed lists as a checklist to confirm and modify the final design to become even more user-centered. Once this initial process is over, the teams went back to DRE and the storyboard they created to ensure the final design can fit into the domestic spaces and seniors’ lives.

5.3.1 Guidelines for easier robot design

Both designers and roboticists thought the guidelines provided enough context, allowing them to approach this complex design topic more appropriately. Designers and the robot expert in Team 08 (T8) told us that the guidelines broadened their insights on robot interaction in domestic spaces as follows: “(Robot expert) I think it lets us consider things that you might not normally consider. It gives you more contexts. It gives you the picture of how robots are going to interact with people.”, “(Designer 1) For me, I would have (drawn) a pretty cane or nice pills dispensers (without guidelines) but I learned about the whole environment thing and that it has to work with not just Scott (the persona) but working with his grandkids and his neighbors”, and “(Designer 2) when I design a product, I just think about the one user and form factor but there is a lot of interaction patterns and relationships between the robot and the users that kind of help me to think about the context”. In this respect, both designers and robot experts found DRE more helpful than the three-step-dimensions. For robot experts, DRE directed them to think of users and design around their needs

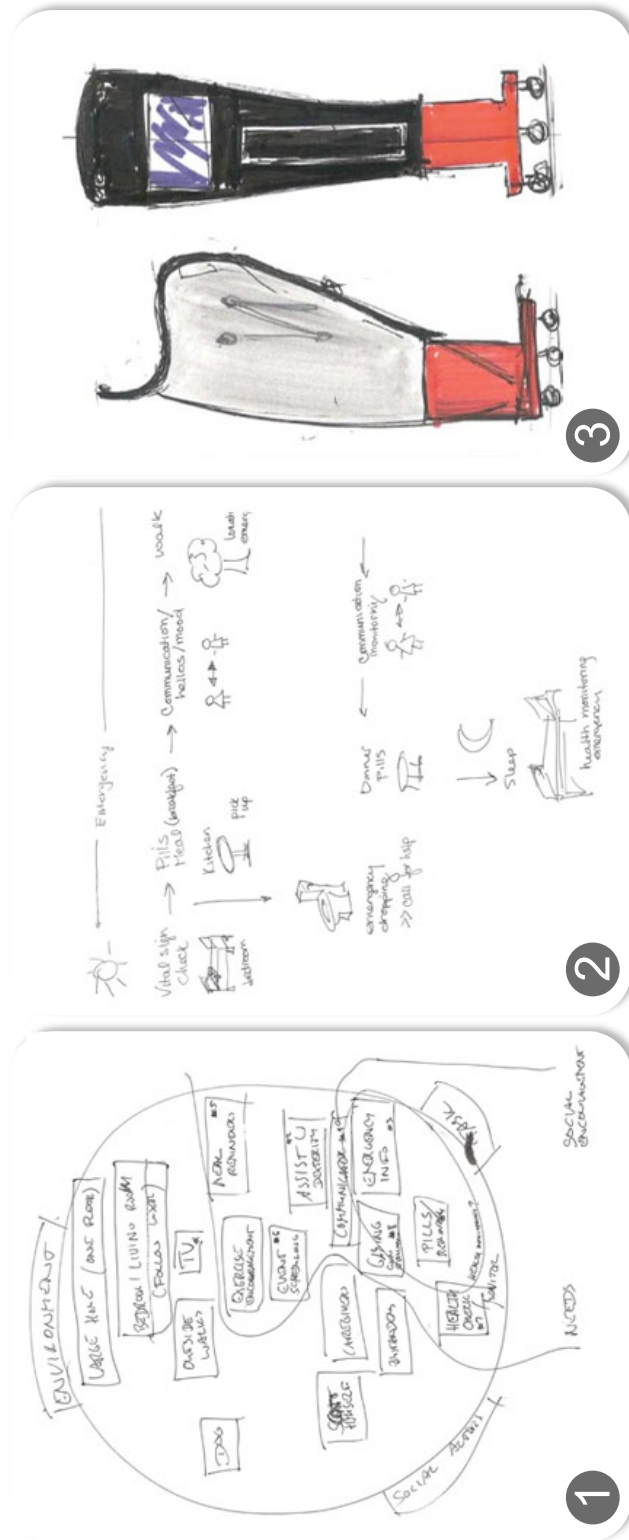


Figure 36: An example of how T4 used guidelines: design requirement generation (step1), storytelling of robot experiences (step2), design construction (step3)

from the beginning, which they felt different from the process they were used to, which the roboticists from T8 noted as "... (a process that focuses more on) what kind of technology they're gonna use, what kind of motor could be used and you forget about how people actually use it". For designers, DRE played as an empowering tool to get them familiarized to this novel design domain. Designers are used to think for the users, and trained to create new artifacts. Nevertheless, they noted that robot design offered a novel experience in that they had to continuously and strongly consider social and emotional behaviors of the technology (unlike a cellphone or a PC), which they had little knowledge of how to approach. One designer in Team 3 (T3) reported he came into the study being scared due to the novelty in the design topic that involves physicality and strong emotional attributes: "...I do mostly web design, so for me it was a big step to worry about physical interactions. And (I worried) about emotions and affect. It is not usually a priority in a lot of design that I do...So that was a lot different for me". The other designers in the same team agreed but said the actual process felt easy because he could approach the entire process from human-centered perspectives, focusing on how this robot would fit into one's life. A designer in T4 responded similarly that DRE tremendously helped "wrap the head around the complexity of the design task at hand".

The teams without guidelines showed various types of design processes; T9 was the only group that took a similar step—design requirement-user scenario-design construction—to those with guidelines. Instead of discussing how robots would fit into a senior's life, they tended to discuss shortly about the tasks robots need to serve and study existing robots that serve similar tasks to be able to design for them. For example in T5, the two designers spent the first hour learning about robots by browsing through the examples on robot expert's laptop. Still feeling confused, they even asked the roboticist to do the initial architectural drawing, after which they added aesthetic forms on top (Figure 37). These teams had design that were functionally

robust but had insufficient time to discuss users. Other groups based their design rationale on favorite sci-fi movies and animations, emphasizing the robots become fun and friendly to end-users; but often lacked technical feasibility. One robot expert in T1 intentionally chose not to provide technical information because she wanted to learn from the designers how to make robots user-centric instead of performance-oriented. Regardless of the design process, they altogether told us the design process was difficult because they lacked knowledge about robots in the home. Roboticists, too, told us that designing for everyday purpose was difficult because it was different from building a factory robot that requires specific forms and engineering requirement to maximize task performance. They could easily answer technical questions, such as choosing between legs and wheels as a mobility platform to designers but did not know how to advise on social features, such as selecting between screen-based input and voice-commands. They desired additional background materials that could inform them how to design for the features beyond performance efficiency and accuracy (e.g., how to design robots to become more socially appealing).

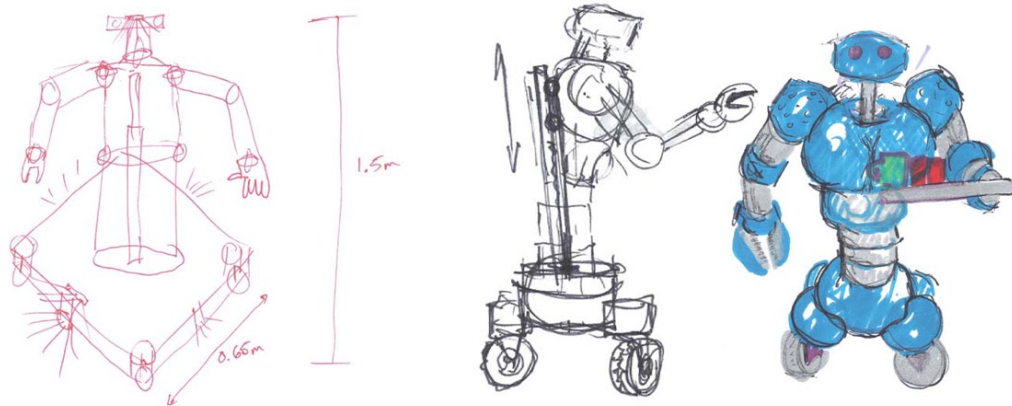


Figure 37: T5's design without guidelines: begins with robot engineer's architectural drawing with addition of aesthetic touches from designers

Thus, I argue that the use of guidelines made the overall design process seemingly easier by providing contextual information of how robots shape experiences with the surroundings at home. The ratings the study participants filled at the end of the study

sessions support this finding. On a seven point scale where seven means very easy and 1 means very difficult, the teams with guidelines rated as *normal* (4.5/7) while those without guidelines rated the process *difficult* (3/7). The difference in these ratings are statistically significant according to T-Test ($t(30)=2.15$, $p=0.4$). Also, perhaps because of the perceived benefit of DRE, study participants showed a high interest in using the same set of guidelines again if they would have to go through the same or similar design tasks; except for two participants, all gave ratings higher than 6 (prefer to use guidelines), making the average 5.94/7. Even the participants who did not use guidelines expressed interest in using some guidelines in the future robot design (4.3/7). Upon asking why they might want to use guidelines, I heard two reasons: one to build a better frame of reference about robot experiences in the home, and the other to reduce the time they spend on negotiating how to go about designing robots.

5.3.2 Guidelines for more emphasis on social design

In addition to this perceived easiness on the design process, I learned that the use of guidelines can change designers or roboticists perspectives toward the design of everyday robots. After the design sessions with guidelines, they recognized the importance of social and emotional emphasis in the interaction experience whereas the participants that did not use guidelines showed less of such a perspective change. I make this argument based on the scaling for the important design attributes for everyday robots on a map (Figure 29). This scaling on a map asks participants to position six design attributes for robots (technical advancement, mechanical reliability, usability, social adaptation, affective interaction and form factor) on a scale that runs from 1 (not important at all) to 25 (critical in robot design). Participants did it before and after the design sessions; and I saw the rating change larger in the groups with guidelines. As shown in Table 14, the teams with and without guidelines

showed contrasting viewpoints on important design attributes. Those with guidelines rated affective interaction and social adaptation much more important after the study; those without guidelines also marked increased importance in these categories but only marginally. For this group, look and feel was the category that showed the most increased in importance. From this rating, I confirm that the introduction of DRE and the holistic robot experiences in the home encouraged and motivated designers and robot engineers to enhance social and emotional aspects in the design beyond this study session.

Table 14: Scales for important design attributes for everyday robots; the scale runs from 1 to 25 where 25 means the most important.

Design Attributes	Teams with guidelines before—after	Teams without guidelines before—after
usable system	20.2—21.9	20.8—21.5
reliable operation	20.8—19.4	21.5—20.7
Look and feel	18.1—18.0	13.4—16.9
affective interaction	14.9—18.5	13.9—15.5 (
social adaptation (e.g., learning)	11.5—15.4	11.3—11.5
technical advancement	13.0—14.1	10.4—12.1

5.3.3 Guidelines for better collaboration

This session reveals different ways designers and robot experts approach the design task. Roboticists wanted to establish the working platform first, and then think about other interactive features as I learned from the HomeMate project (operation-communication-engagement level). In general, robot engineers agreed to this categorization by saying “(T3 Roboticist) the categorization of operation-communication-engagement) made a total sense yeah. Because you have a lot of constraints operating robots. So (in the operational level) it rules out a lot of different possibilities. And then you go to communications and engagement..it makes a lot of sense”. In contrast, designers begin by thinking toward abstract analogy or metaphor, and find feasible

options to realize their concept. For example in T1, designers tried to achieve friendly interaction, which led them to talking about pet analogy and developing touch as the main interaction that was often how pets and owners communicate to each other. It led the designers to discuss how they desired warmth felt during the touch, and then finally down to rubbery material as the skin. Seeing this process, the roboticist in T1 told that it was unfamiliar ways to unpack the design thinking as she told, “It’s really hard for me. It’s a robot. My robot is made up of all the pieces and that’s all I see it at. For me to work with the concept flow, that’s very difficult. I never thought to start with an analogy of a bear or a dog”.

I learned that the guideline usage may mediate among these fundamental differences during the design process, producing better group collaboration. The guidelines put much emphasis on human-centric views, which could become an empowering tool for designers to negotiate with the roboticists to try and restrain the team from focusing on specific technologies. For example, the robot expert in T4 started unpacking the possible platforms for manipulation during the early ideation stage, and designers used the guidelines to draw consensus on user-centric process:“(Designer 1)...for a design process I want to think about acceptance and interaction first and then about functionality...I come in as a non-robotic expert, and I really want to step back from the (technical) solutions...and have the freedom to say what could break down the (adoption) barriers”. This pattern of negotiation did not appear as much with the teams without guidelines (at least to the extent of this study); it was largely influenced by participants’ personalities and dominated by whoever had the strongest voice in the team. For example, the designers in T7 liked the idea of telescopic arms, which the roboticist did not find feasible in ten years of time. She expressed her concern several times, but the final design included telescopic arms.

The impact of guidelines in bringing the team together became clearer in the way they developed the concepts. The teams without guidelines discussed design

requirements (e.g., robot tasks) together and then took individual time to draw out their visions, which lasted about an hour and half. During this time, designers took the lead role, and robot engineers acted as a Q&A person instead of having active roles and opinions on the concept. All teams but T9 worked on the design ideation individually and later voted on the ones they liked. With time constraints given in this session, they could often not articulate the design in depth (i.e., the size of the robot, primary control methods and more). Even the designer in T9 told that he wanted some guidelines given the length taken into the negotiation of the design process at the beginning as said by one designer, “I would have preferred the guidelines because most of our teamwork was to come up with the guidelines”. The teams with guidelines worked differently. All teams chose one primary designer who had the better drawing skills, and other team members supported the shaping of the robots verbally or by providing rough sketches. All groups with guidelines finalized their ideas before presenting to me, and it seems possible because they went through the guidelines for the last time to confirm and modify their design concepts. At the minimum, the design concepts had the depth of what was suggested on the guidelines: holistic interactions and design details with regards to operation, communication and engagement.

Apparently, the mediation of varying degrees of interests and conflicts appeared to make them feel that they could talk to each other better. Participants who used guidelines told that it helped them stay on the same page to meet the design goal as nicely reflected by T3 participants: “(Robotist) One thing that was really helpful with the guideline document was that it made the communication very easy. (Designer 1) We all knew what to think about and we were all thinking about it at the same time. It was very easy to be on the same page. I can see if this document were not present, for me I would think about face and for him to think something else. There are so many aspects to think about...and this step-by step process makes me think

about one thing and move onto another”.

5.3.4 Areas of improvements

Generally, guidelines were well-received among the participants. Upon asking to rate their willingness to use the same or modified version of the guidelines (where 7 means strongly prefer to use guidelines again), all but two gave ratings higher than 6 with overall average being 5.93/7). Even some participants who did not use the guidelines rated that they would want to use guidelines if available with an average of 4.3/7 (ranging from 2 to 6). I did not share the guidelines with them because the three hour study duration was too tight to allow for the explanation. So this rating is based on their desire to have better structured instructions, not necessarily like the ones I created for this thesis. Participants gave positive ratings for both effectiveness (5.6/7 where 7 means very effective) and informative (5.3/7 where 7 means very informative). Additionally, participants appeared satisfied with the mechanics of the guidelines including, content clarity, content organization, and DRE comprehension as shown in Table 15.

Table 15: Rating scores for the design guidelines

Categories	Rating scores (1=very poor, 7=excellent)
Effectiveness	5.6/7
Informativeness	5.3/7
Content clarity	4.9/7
Content organization	5.3/7
DRE comprehension	5.3/7

Despite these positive initial responses, this study surfaced areas for improvement for the guidelines. The biggest downfall of the guideline usage was the compromised diversity. The rigid step-by-step process was helpful to consider the breadth of user-centered contexts, however restrained some designers’ diversity to go outside the box. Designers were comfortable utilizing DRE and visualizing the experience, but some of them expressed stressed in the next step, which was to build robots following the three

dimensions with some specific design considerations. Roboticists noted that they were comfortable with the design progress of operation-communication-engagement, but this inductive ways to assemble design was too rigid for some designers as shown by their metaphoric and abstract approach with what they want to create. In fact, one designer in T8 expressed stress of the need to following and interpreting every lines in the guidelines (as the roboticist in the team insisted), and eventually said “I am just going to start sketching because it makes me feel better”.

Overall, the design workshops show five ways to modify the guidelines:

1. First is to emphasize DRE as the main portion of the guidelines, and to decrease the role of 3-dimensions and specific instructions as a checklist for human-centered design. Roboticists, while agreeing with the categorization of the three dimensions, told the specific instructions under respective dimension were too domain specific (Roomba) and need more body contents based on more case studies to become truly useful to design a broad range of everyday robots. As one example, the robot expert in T4 told the design instruction for “expressive and random movements for the robot in the beginning that become efficient over time to show the capability of learning” were the right case for Roomba, but should not be treated as a general statement because some domestic robots perform critical daily activities such as delivering medicine that cannot have rooms for errors.
2. Second is to demonstrate the mutually influential relations among the three dimensions; the design does not have to start with operation but can start with engagement and move down to operation. The design examples from the study (i.e., warm concept to rubber skin material) should demonstrate this aspect more clearly.

3. Third is to begin the design process without guidelines to maximize the free-form thinking, and then introduce guidelines to balance against user-centric and technically plausible ideas.
4. Fourth, the study participants suggest that DRE should be more informative and directional. DRE currently presents five relationships (R1-R5) as tools, mediators and agents with environment, social actors and tasks, which was fairly easy to comprehend after all (as supported by the rating in Table 15). Yet, they wanted more explanations and examples of how to apply these relationships. For example, they wanted the numbering of the relationships (R1-R5) to reflect the order to consider. Indeed, two groups told me that they could not determine R2 (how robots influence the physical environment) until they thought through the form, mobility methods and manipulation mechanism, and hence should be noted to consider the last or to come back to DRE after the detailed concept development.
5. Fifth and last, considering the time pressed development process, they requested interactive form of the guidelines such as showing the empirical evidence of each relationships when clicking or hovering over the item. This way, it would be easier for them to understand better how these relationships matter in the robot design.

5.4 Summary

In this chapter, I presented the results of guideline assessments and discussed the benefits and areas of improvements of the guidelines. The use of guidelines offered several upsides in the design of everyday robots. First, it helped the actual design outcome to balance user-centered perspectives against functionality. Second, it mediated the perceived difficulty in the design process elicited by unfamiliarity and complexity (i.e., motion) of robots as a design topic. Third, it strengthened the group dynamics

among the designers with various types of backgrounds. The participants who used the guidelines (including both design practitioners and robot experts) noted that they particularly liked the part that the guidelines provided a visual frame (DRE) that allowed them to reconstruct the user experiences with robots and could focus on how it would fit into a person's life. However, this study also shows that the guidelines need more improvements particularly in the way it can promote creative ideas. I suggest the guidelines need to emphasize the parts that help visualize user experience, and reduce the tone in the parts that present specific design choices to increase generalizability.

Thus far, this thesis has explored the initial step towards establishing design guidelines for everyday robots. In the next chapter, I revisit the initial research question this thesis has proposed, and conclude with the answers and insights I have learned.

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

The recent trajectory of everyday robots presents that robots will play larger roles in our daily lives in the home, serving tasks for healthcare [16], cleaning [34], entertaining [36] and more. Researchers note that the key for the successful acceptance of everyday technology relies much on its design to support and blend into peoples everyday lives[88, 24]. Robot is a complex entity that interacts with us in multifaceted levels: physically, intellectually, socially and emotionally. Designers or robot engineers' intuition alone will fall short to create robots that can really penetrate the mass market and promote people's lives. However to date, few have explored how to support the design of such robots to become better accepted. This thesis have undertaken an initial step towards the robot design discourse by proposing a set of guidelines.

6.1 Thesis Summary

The thesis have discussed the design guidelines for everyday robots in four steps.

For the *first step*, I identified that there is a need for guidelines designated for everyday robots to overcome design challenges unique to this design domain (claim 1 in Section 1.1.1). Related work suggests that robots possess unique social and emotional characteristics that other home interactive technologies such as a phone or a TV did not strongly portray, and therefore the existing interaction design guidelines are perhaps not as applicable. The ethnographic observation in HomeMate development process adds to this finding that designers feel challenged by this topic because they possess little frame of reference about how this novel technology can possibly reside in domestic spaces. These points highlight that design guidelines are necessary to a)

help reflect the unique characteristics of robots to blend in with people’s lives, and b) provide a concrete frame of reference to designers to fill the gap of their knowledge in everyday robots.

These needs show that the guidelines need to inform lived experiences with robots in the home—from adoption to sustained use to learn the interaction after novelty excitement fades away (claim 2 in Section 1.1.1). That said, as the *second step* I began to investigate how people actually live with robots by undertaking a series of interviews, online surveys and long-term field observations. Due to the limited availability of everyday robots, these studies focus on the experience with one type of such robots: vacuuming ones. To broaden the focus, I conducted a generative activity in which people visually depict the robots they want to have for their homes.

Collectively, the study results show that people form intimate relationships people with their robots induced by the physical movements and less anticipated behavioral patterns. It leads to manifesting the fundamental changes in household routines; people start seeing manual drudgeries as fun time to play with robots. However, not all households have accepted robots; for those who felt that the robots’ form was too obtrusive in the environment or robots’ inability to adapt to dynamically changing physical environment such as clutter thought it required more burden than they wanted to invest on supposedly self-sufficient technologies, and hence discontinued using. The design study adds to these findings that people want to balance autonomy against manual control for the robots that perform complex daily tasks such as home security, and they want to feel in control of this agent by making it smaller than their height. Essentially, these studies inform three key attributes (environment, social actors and intended tasks) that interplay with robots to influence positive and negative users’ knowledge. Robots are organically connected to these three attributes as a tool to perform tasks, as a mediator for social changes at home, and as an agent to directly engage with people-which.

Because the study goal is not only to uncover the design insights to make robots more acceptable, but to frame them in the ways that robot developers with diverse backgrounds can easily access and comprehend (claim 3 in Section 1.1.1), I have taken the *third step*. To gain the insights, I have participated in a real-robot development of a senior-care robot (HomeMate). The participation in HomeMate design process show that the guidelines need to focus on two things; one is to construct holistic robot-experiences in the home and visualize the complex social interactions (and leading to the creation of Domestic Robot Ecology); the other was to draw out detailed design requirements with some structure of which I learned the inspiration from how real developers consider the design, such as beginning with operation dimension and moving on to communication and engagement dimensions.

As the *fourth and final step* within the scope of this thesis, I assess if these guidelines make sense in the robot design process. I simulate the early design development process of senior-care robots (like HomeMate), and invite designers and robot developers to create concepts with and without guidelines to evaluate the usefulness and potential areas for improvements. The result of this experiment shows that the guidelines helped approach the design to become less technology-oriented and more human-centered (claim 4 in Section 1.1.1).

These four steps support the following thesis statement: *Design guidelines that account for social and lived experiences of robots in the home can improve the long-term adoption and use of consumer-domestic robots*. However, the use of guidelines appeared to compromise creative thinking during the design process, which leaves spaces to consider further in the future how to incorporate human-centered values with innovative ideas. I discuss more about the future directions this study can lead to in the following section.

6.2 Limitations and Future Work

Overall I felt the task of establishing design guidelines for an emerging yet novel area was ambitious. This thesis was constantly challenged by the very limited number of real-world examples that I could even use for my experiments, and relatively a smaller body of related work that discuss human-centered design of everyday robots that I could learn from. I have undertaken a various types of user studies that involves qualitative, quantitative and design-based co-creation methods, which produced a large amount of user data to complement these constraints. Still, I feel that I have addressed only the very tip of a massive iceberg. I hope this work can initiate some research inspiration for others. I truly believe the well structured guidelines can benefit the robot design until everyday robots become a natural part of our lives and therefore designers would not have to wonder what the experience would be to live with those technologies. I often questioned myself how I would take on from this study if I ever make a glorious return for the second Ph.D. And below are some suggestions for future work that I would try and complement the limitations I had for this thesis.

Firstly, I would explore the domestic lives in further depth, and relate cultural specificity, gendered characteristics, economic status might be incorporated into the design guidelines. The current initial guidelines view homes in homogenous perspectives, and fall short to address how men and women, or how adults and children might want and need different types of robots. The empirical studies in this thesis suggest that the gender of the primary users, the number of householders, the presence of valuable artifacts that cost a lot and the existence of children and pets were the attributes that influence the way people accepted and rejected vacuuming robots. It implies that these factors need to be considered into the design of everyday robots including form factors, tasks and more. One example is the tasks that robots serve. In the sketching study reported in Section 3.4, I identified how men generally wanted

a robot that would serve utilitarian manual tasks, such as delivering tools whereas women wanted a companion that could teach her how to invest her money and fixed cocktail when in a bad mood. While my empirical studies suggest insights how the specific characteristics in domestic lives may influence the robot design, I call for future studies that focus on each attribute (e.g., gender or household composition) to identify how to reflect domestic variability into design guidelines more accurately.

Secondly, I would like to extend the scope of guidelines to other cultural contexts. The current version is based on American homes and householders' life styles. The lessons and the guidelines drawn from these examples may not apply to the lives in Asian or European homes. The studies of vacuuming robots conducted in Korea have demonstrated the high threshold of doors as one big navigation hurdle [53], which in U.S. homes were barely reported. Also, other factors, such as the size of the home, the amount of stuff owned and the prevalence of materials (i.e., carpets, rugs, tiles etc) may induce cultural responses. Additional to these physical differences, robot researchers have identified that cultural backgrounds influence the fundamental ways that people see robots; for example, Asians have higher tendency toward ascribing lifelike qualities to robots and treat them as companions because of the teachings from Buddhism and Animism that consider all surrounding parts of our lives as living entities [27, 61, 59].

Thirdly, I call for thoughts on the ways we can design everyday robots. This thesis is focused on suggesting human-centered design approach that tries to build design guidelines by thoroughly understanding how people live with everyday robots. In this thesis I contend that this approach is useful in reconstructing human-robot experiences when designers or robot engineers are not familiar with robots in the home. However, not all everyday robots are made in human-centered design approach; many of the current domestic robots are created with designers' intuition. This thesis has not identified all existing design methods for everyday robots, and made enough

comparison to identify whether human-centered design has advantages over other design approaches, and if so what they are. The limited number of sites that develop everyday robots might be a hurdle to seek answers to this question. However in the future when robots have become a common domestic artifact, it might be a worthwhile agenda to explore further.

Fourthly, I would add more case studies with different types of robots to add to the body of the guidelines. Currently, these guidelines are based on two types of robots (Roomba and HomeMate) that almost represent two extreme examples of everyday robots. Roomba is a simple unit that does identify the environment minimally (i.e., random bumping, turning and sweeping), has a simple round and flat form factor, and only responds to human input and not autonomously trigger any interaction on its own. HomeMate is different in all these aspects. It understands the environment and makes precision navigation from a room to a room. Also it identifies each household member and can offer customized service. It triggers a number of autonomous interactions, such as reminding time to take pills. Further, the form factor has anthropomorphic shape that has several parts that adjust (i.e., height) and fold in and out (i.e., arms). Concisely put, Roomba is the simplest form possible as a robot while HomeMate being the counter example. To make these guidelines more plausible, I need more case studies from various ranges of everyday robots that fall in between these extreme cases. Among those that are in the market, I see two types of robots that could become a helpful addition. One type of robots needs to have at least one utilitarian task with designated social features, such as being able to talk. Rolly or Miro that combined speakers for music player with entertaining physical motions and expressive interactions, and Clocky that combined an alarm clock and robotic movements. These are arguably intelligent and autonomous robots, but certainly stand in between Roomba and HomeMate in the way they bring robotic essence to the artifacts we use in our everyday routines. The other type of robots has

more sophisticated cognitive features with less stress on the physical manipulation. Some examples include robots such as iRobiQ that displays emails and plays karaoke (<http://www.irobibiz.com>), and Nuvo that performs home security and exchanges conversations (<http://nuvo.jp>). These robots might provide interesting user insights in the way they not only replaced the existing domestic task, but create new social tasks by actively and autonomously engaging with people. I expect the addition of case studies could incur the changes in the current guidelines (particularly the DRE), at least in the following ways:

- First, I suggest a sixth relationship in DRE: an *agent* that interacts with other intelligent appliances at home. This particular relationship did not appear in the Roomba study because this robot did not have networking capability to communicate with other robots. However in future, I can easily envision a security robot communicating with wireless cameras and other robots in the home (as depicted in [21]).
- Second, robots would act more as a *social actor* than as a *tool*. Current service robots primarily act as a tool to perform a task based on user needs. For example, people run Roomba when they want to clean. In the future, robots will be expected to handle complex tasks that other smart technologies manage, such as remembering and notifying schedulers, and offering personalized service based on user behaviors and user profiles (illustrated with detail in [42]). It means that future robots may act as social actors that determine and perform the task autonomously without user input.
- Third and finally, I envision that robots would act less as a mediator that requires people to modify their existing environment. With increasing capability to map the house and to track the navigation paths, future domestic robots will smartly sense and avoid obstacles. They may even pull the mechanical

arms and adjust the environment themselves as needed. More case studies with other consumer robots would help verify these projected addition to the current DRE. Nonetheless, the initial attempt to create DRE in this thesis would elicit scholarly interest among other researchers about how to incorporate long-term interaction into the design of everyday robots.

Fifthly and finally, I want the future work to focus more on contributing to build the detailed guidelines under each dimension of operation, communication and engagement. While I feel the biggest contribution of this thesis is the depiction of holistic interaction experiences with everyday robots, I see the detailed design instructions on forms, interaction modes and socio-emotional features as the weaker part of the guidelines, primarily due to the limited case studies I could perform. It would easily be anyone's lifetime's work to address all these areas in depth. However, one potential area for robot interaction design that emerged from this thesis but still has received less attention is the manual control interface/interaction of everyday robots. The user research including the studies with Roomba and the generative sketching study implicate that people do want to have some control of the robots. The desire appears stronger as the robots performed more privacy and safety related tasks, which is the trajectory anticipated by International Federation of Robotics [66]. Fully autonomous robots, even when possible, will not be the optimal solution for domestic environments because of the household members who clearly want to govern things according to their preference. Some researchers have begun the exploration. One researcher created a system to fine-control domestic robots using a line-stroke on a digitized surface [73], which I thought could be an interesting way to customize and plan for the robot activity—at least more fun than Roomba's remote that only allows you to enter time and date to initiate the operation. The other researcher created interactive paper cards with a task that a robot can perform, allowing people to easily control the robot by placing the cards in the place that they want the robot to do

an assigned activity [96]. The greatest benefit of this magic-card system is to allow people to plan multiple tasks for robots without having to learn a complex interface. Another researcher utilized the timeline interface frequently seen in a sound and video editing program, and turned it into a robot-orchestrating interface [80]. By moving up and down the timeline, people can control the speed of the task, and add or delete action points on the timeline to manipulate more than one task. One can even add the timeline to control multiple robots easily. Despite the interesting design concepts, these studies lacked the empirical power to support why such systems could play a crucial role for robot acceptance in the home. Hopefully, the results from my robot studies can motivate to explore how autonomy inherent to robots can combine with interactive manual control to maximize the usefulness in the little predictable environment such as the home.

6.3 *Broader Reflections*

Upon completing this thesis, I want to share the insights I learned beyond the immediate boundary of creating design guidelines for everyday robots. Here I reflect on the overall thesis, and situate my work along the lines of scholarly work in Human Centered Computing. Based on this, I discuss what my work broadly reflects to:

- Designing for smart-home technologies
- Re-thinking the design process of new technologies

6.3.1 Designing for smart-home technologies

One implication that my research of domestic robots shows is the forecasting of how the autonomous technologies—those that can make decisions without human input or control [52]—might change the paradigm in the design of interaction experiences. Recently, a number of scholars have noted the changes in interaction design from screen-based experiences to embodied and contextually relevant experiences to our

lives (e.g, [7, 1, 24]). This change is largely because of the advent of portable and networked devices, such as the smart phone that allows ubiquitous access to technologies in everyday settings, making them a natural extension of our daily routines. This transition shifted the focus of interaction design from easy and efficient performance to broader theme of ‘making it fit by achieving invisibility in use’.

With robots, achieving invisibility-in-use has become challenging; robots navigate physical environments, encounter clutter and new objects, and interact with various types of people and pets in the home. Differently put, technologies with autonomy and mobility stand out in the environment and remain visible in use; they physically move around the home and initiate interactions and engage with people proactively. Further, the little controlled domestic environment including clutter, pets and furniture causes accidents in operation, which leads to human attention for continuous maintenance. Thus, autonomous technologies will inherently remain visible during the interaction with people. Roomba and other robotic appliances are the forefront examples of the autonomous agents but other systems are becoming smarter every day. Now we see home-healthcare products that can monitor behaviors of seniors and determine when to call for an aid on its own (e.g., GE’s Quietcare), running shoes that customize songs of portable music player to best match the exercise speed (e.g., Nike plus) and more. That said, I contend the introduction and growth of autonomous artifacts will elicit a different paradigm in interaction design; the pursuit of invisibility in use will be insufficient to embrace the dynamic and complex interaction patterns these autonomous agents produce. Then, how should we design interactions for the autonomous technologies to become incorporated into domestic spaces without making their visible nature obtrusive?

The studies of Roomba and HomeMate suggest that elicitation of social relationships might be one answer, making this technology more than a tool and a natural part of the social circle in the home. Robots’ implication that it thinks on its own

leads people to apply social norms and treat them as lifelike agents, such as giving names, referring to it in a gendered term and ascribing personalities. Also, householders created social activities around the autonomous robots—entertaining guests, walking their pets and more. As noted by Forlizzi [32], autonomous robots were accepted as a social being, and it complemented the visible presence because people felt as if they had adopted a pet-like being. When autonomous technologies were considered a legitimate part of the social circle, householders considered the amount of adjustment and maintenance as a process of care-taking as anyone would do to their pets. I see it as the forthcoming paradigm to aim for interaction design of autonomous technologies: interactions that go beyond the theme of ready-to-hand, and pursue the notion of *social compliance*. Based on this thought, I created DRE in which I captured the social connections robots make in domestic space.

The pursuit of *social compliance* in interaction experiences may influence various aspects in the design. My thesis informs that people cared less about the mechanics of interaction (i.e., pressing buttons, giving voice commands and showing gestures) and more about how it fits comfortably into the existing social norms. For instance, participants talked about interaction methods that can ascertain their ownership of autonomous agents such as a complementary remote control and an emergency button to end operation. Also, they described ideal robots as those that could portray politeness and compliance by bowing and nodding to return the feedback. In the studies of robotics, social accords has become an important theme in interaction design; researchers have studied how robots should approach to make people comfortable and how robots should recover errors to appear acceptable and more. Reflecting on the growing trend of smart devices in the home, I argue that the consideration of social accords would become an important theme in the design of home technologies that are broader than robots.

In sum, my thesis shows that robots bring in different interaction patterns than

embodied and ubiquitous computing technologies do. Robots enter our households as an active agent, which leads to my argument that a different design paradigm is necessary to incorporate this explicit visual agency of a robot. I suggest with autonomous agents that making it a part of the existing social relationships (like adopting a pet) was one way to think about designing interactions for them.

6.3.2 Re-thinking the design process of new technologies

Robots are bleeding edge technologies; people rarely have experiences of using robots in their home or in any other social settings. Studying the design of such future-forwarded object gave me an opportunity to reflect on the role of designers in the creation of novel technologies.

This thesis presents a case study where designers were asked to create senior-care robots based on given user information. Although designers are those trained to think future forward, they found this task difficult because they had minimal knowledge of robots and the user experiences it brought. The usual user research that analyzed the target population and the potential needs were insufficient; without their own repository knowledge of the design object, they could not bridge the user needs into creative solutions. The outcomes were either too far fetched to become feasible or too deep in technical details and less about users. In contrast, the designers who received guidelines and could fill in the gap of their knowledge of robot experiences in the home could bring in more solid solutions that are both user-centric and feasible.

It shares an insight about the widely embraced rhetoric of user-centered design that focuses on employing users into the design process as much as possible while asking designers and engineers to restrain their own voices that are often considered biased. However, this study shows evidence that designers' existing knowledge can be equally important to including user knowledge, which acted as a frame of reference and a repository for creativity. It leads to the following question of how to balance

designer insights against user opinions. I find it particularly important to consider for the design of cutting-edge technologies. Users are often technically naive and may not offer the deep insight that designers need. For instance, I want to learn what people want for a future robot for the home, and start by asking as an interview question. The results were not very helpful because participants told similar to “I want a robot that does every kinds of chores for me”, which led me to change the study method to sketching-based activities. It resulted in more concrete outcomes and ideas, but some participants still felt uncomfortable to give opinions on topics that they knew so little.

Learning from this lesson, I chose to design HomeMate by relying on designers for the early development and minimize user involvement. I began by collecting user requirements based on existing literature in related fields instead of directly talking to users that I would have normally done. Then, I invited experts—design practitioners and robotics experts—for ideation, which was presented in Chapter 5. The next step is to bring in a small number of potential users and ask their opinions on the initial form factors, tasks and other interaction concepts. As the design develops, ideally more users will be involved in the process. Overall, my strategy going into the design of HomeMate, a new form of home technology was to maximize expert knowledge in the beginning and wait to bring in naive users until design has developed concrete enough to make sense to them. The principle of user-centered design recommends to bring users as early into the design as possible, which would work for incremental changes from what has existed already (i.e., designing for newer printer). However, technologies advance faster, and designers will be asked to create ‘innovative’ artifacts that can even elicit a new lifestyle (i.e., iPad), and they will likely encounter cases where they have to carefully choose when to bring in users.

In sum, the experience in designing cutting-edge robots makes me re-think about what it means to have a user-centered process and how a designer can play a role in it.

My study suggests that the user-centered design process may need to vary depending on the familiarity of the design topic. If the design pushes for technological innovation that barely exist in our lives, it might be more useful to rely on designers for some early design decisions. Here, I try to elicit discussion rather than impose an answer about a designer's role. In the paper 'Usability considered harmful' [40], Greenberg and Buxton argue that existing usability metrics may not be the best way to assess innovative products that have not yet entered consumer market. Similarly, I want to raise a point that the established design process may not always be the right path to take for the design of yet-to-be-created.

6.4 *Concluding Remarks*

To conclude, I contend that this thesis has opened up an important discourse for the human-robot interaction and broader related communities: how we live with robots in the home over an extended period of time, and what it implicates for the robot design that can increase user acceptance. I suggest the depiction of holistic user experience (DRE) as an initial step to this answer, and the assessment shows positive response to this direction in the way it can reinforce human-centric views during the concept generation.

Thus, I have shown that the guidelines that accounted for lived experiences can positively influenced the everyday robots to become more accepted. I acknowledge that this thesis only initiated the discussion among the interested researchers; more case studies and in-depth exploration of interaction experiences are critical to build the critical mass for the guidelines. I hope my thesis can become the baseline for these upcoming studies. Further, I see these efforts altogether produce a continuous momentum for robots' world domination growing benefits from these unique robotic agents.

APPENDIX A

DESIGN GUIDELINES

The appendix includes the design guidelines proposed in this thesis. First, I introduce the short version (2 pages) that designers can use to quickly refer back to the guidelines. Then, I present the long version (20 pages) that contains detailed descriptions of DRE and the pertaining design instructions with examples learned from the empirical studies. Again, I stress that these guidelines are an initial attempt to support the human-centered approach in everyday robot design.

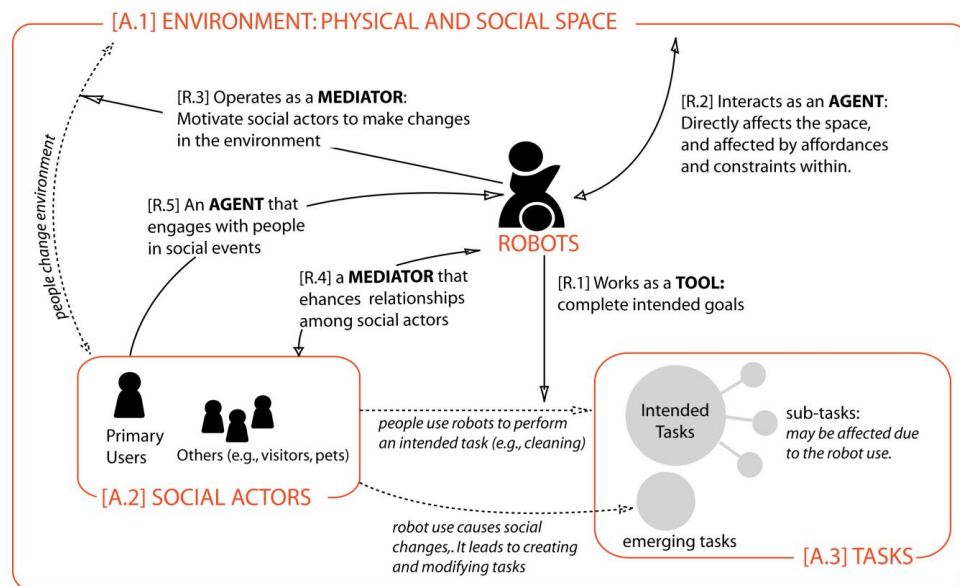
The information in these guidelines are equal to those presented in Chapter 4. This appendix is the presentation of how I would put those guidelines as a comprehensible package to designers. Also, this is the package distributed to designers and robot engineers who participated in the evaluation of the guidelines (Chapter 5)

INTERACTION DESIGN GUIDES: EVERYDAY ROBOTS

Robot interaction design for everyday spaces is a complex activity. Designers should understand how robots' mechanical structure and intellectual capabilities marry seamlessly with the surrounding context. To achieve, we propose two steps in the interaction design.

Step 1. Frame Holistic & General Concepts for the Interactions

- Articulate three key interaction attributes: Environment (where), Social Actors (who), and Tasks (what).
- Robots have five types of relationships with these attributes (see below for detail).
- We captured these three attributes (A.1, A.2, A.3) and five relationships (R.1, R.2, R.3, R.4, R.5) that occur during the interaction with a robot in a comprehensive model (see below).
- Using this model, create a storyline of how the robots you design up will work.



[R.1] A tool to perform tasks: robot replaces the manual labor to improve the quality of life. (e.g., a robot to “clean”)

[R.2] An agent that directly impacts the surrounding environment: robots physically affect the environment. It may move the location of objects in the environment (e.g., breaking mirrors, damaging carpets) and more.

[R.3] A mediating factor that motivates people to make changes in the environment: People make changes to incorporate robots into their home, such as moving furniture to make more rooms for robots to navigate. However, excessive amount of changes can feel burdensome and discourage people from adopting robots beyond novelty excitement.

[R.4] A mediator that enhances social relationships among household members: Robots often became a new means for social activities. People deliver a surprise gift using a robot, make race-tracks to compete with neighbor’s robots, and create videos/stories of robot usage to share with friends and families.

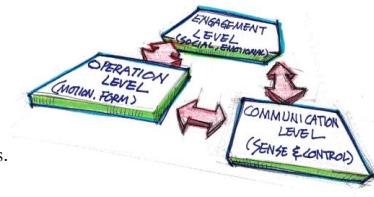
[R.5] An agent that engages with people socially: people ascribe lifelike qualities to a robot, and directly engage in social activities, such as giving names, genders, and personalities. It happens even when the robot does not look similar to any lifelike beings. People perceive lifelike qualities from how robots think independently and move autonomously.

INTERACTION DESIGN GUIDES: EVERYDAY ROBOTS

Once you have the holistic/general concept from Step 1. based on the robot interaction model (3 attributes and 5 relationships), now it is time to get to thinking about more detailed interaction!

Step 2. Construct a Detailed Interaction Experience

- Think of robot interaction from three perspectives: operation, communication, and engagement.
- These three aspect will reveal the complexity in the amount of interactions to consider. Yet, these three aspects are closely connected, and thinking of one aspect can naturally impact others.



[Guiding Points for Operation Dimension]

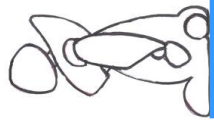
1. Plan paths for both global (entire house) and local (certain areas) operations.
2. Change robot motions over time from being fun to being efficient in task performance.
3. Plan motions sensitive to height and orientations.
4. Balance visual compatibility and visibility .
5. Reduce operation noise from robots, and hence allow multi-tasking from householders.
6. Plan for a broad range of operating environments to allow smooth operations in all (floor) conditions.

[Guiding Points for Communication Dimension]

1. Allow both autonomous (let robots do tasks) and manual control (let me control robots go to the living room).
2. Provide an interface that tracks and logs robot activity for troubleshooting.
3. Modes of interaction/control: voice command most preferred. But think of controlling robots where voice cannot reach.
4. Learn for personalized communication (e.g., recognize personal favorites, names, gender), and show this learning process.
5. Consider safe and secure services to increase its utility and usefulness in everyday settings.

[Guiding Points for Engagement Dimension]

1. Provide long-term engagement. Make it less predictable and lifelike.
2. Create personally meaningful relationships through customizations.
3. Enhance entertainment and sociability and allow it become a companion-like being.



INTERACTION DESIGN GUIDES: EVERYDAY ROBOTS

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User Research / Design Recommendations

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Georgia Institute of Technology 2009

1. INTRODUCTION

Demand for robots that perform everyday tasks grows rapidly. Researchers note that the key for the successful acceptance of everyday technology relies on a design which supports and blends into people's everyday lives. To date, robot design focuses more on pursuing technical advancement than on user experience. We address this omission by proposing guidelines for the interaction design with everyday robots.

Robots possess unique characteristics. Unlike other computational technologies that base upon screen-based interactions, robots possess physical body parts that move autonomously. It broadens the dimensions of interaction, and hence makes the design process more complex. Below, we list **three challenges** brought by the unique characteristics of robots.

[1] **More interaction modality:**

- In the computational artifacts, designers consider the alternative mode to interact as: vision, speech, sound, and tactile (binary touch).
- With robots, the range of alternative interaction modes grows larger.
- Gesture (or embodied motion) takes a larger role in communicating with robots.
- Further, haptic (continuous touch) becomes an important mode of interaction because people encounter physical interactions with robots.

[2] **Bi-directionality in interaction:**

- For computational artifacts, the interaction took one direction: input from human and output from computers.
- Robots can sense, process, and act according to the self-determined paths, which makes the interaction multiple directions.

- Robots, just like people, can initiate and return the interaction.
- For designers, it means that they have to treat robots not as an artifact, but as an agent. It makes the task more challenging because the possible number of interaction scenarios largely increments.

[3] **Cultural sensitivity:**

- Perhaps due to robots' agency, studies show that people show higher tendency to apply social rules to robots and expect more human-like engagement.
- It implies that the robots not only interact user-friendly manners, but also correspond appropriately to the pertaining cultures.

Going forward, we present two steps to help guide the interaction design of a robot that can be best incorporated into our everyday space, such as the home.

2. INTERACTION DESIGN STRATEGIES

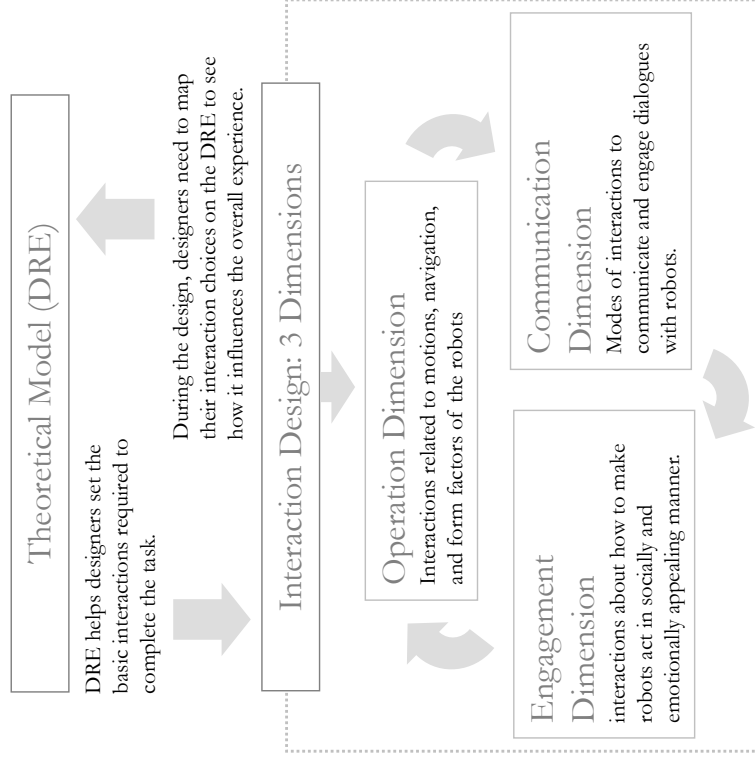
In presenting design guidelines, we suggest two iterative steps.

First, designers need to understand broader contexts of how a robot would interact with the environment, people, and other artifacts in an everyday setting. To better explain this holistic picture of the interaction, we present a theoretical framework, called the [Domestic Robot Ecology \(DRE\)](#).

Second, we provide actionable design guidelines that designers can refer to as they create robot interaction, such as how it moves in a certain environment. We divide these guidelines into three dimensions: [interactions for robot operation](#) (e.g., mechanical structure and form factors), [interactions for robot communication](#) (e.g., dialogues), and [interactions for social and emotional engagements](#). These dimensions reflect the order of interactions related to low-level and mechanical operations, interactions related to controlling those operations, and finally interactions related to enriching the interactions. We did so to allow designers to better structure the complex nature of the robot interactions.

We call these steps iterative because designers will interchangeably use both steps to refine the ideas for robot interactions. First, the theoretical models will help designers set the basic pictures required to complete a given task. Then, as designers develop more detailed guidelines following the three levels, they will re-shape the holistic pictures of the robot interaction according to the theoretical frame. These steps will reciprocate until designers reach conclusions.

HOW IT ALL WORKS

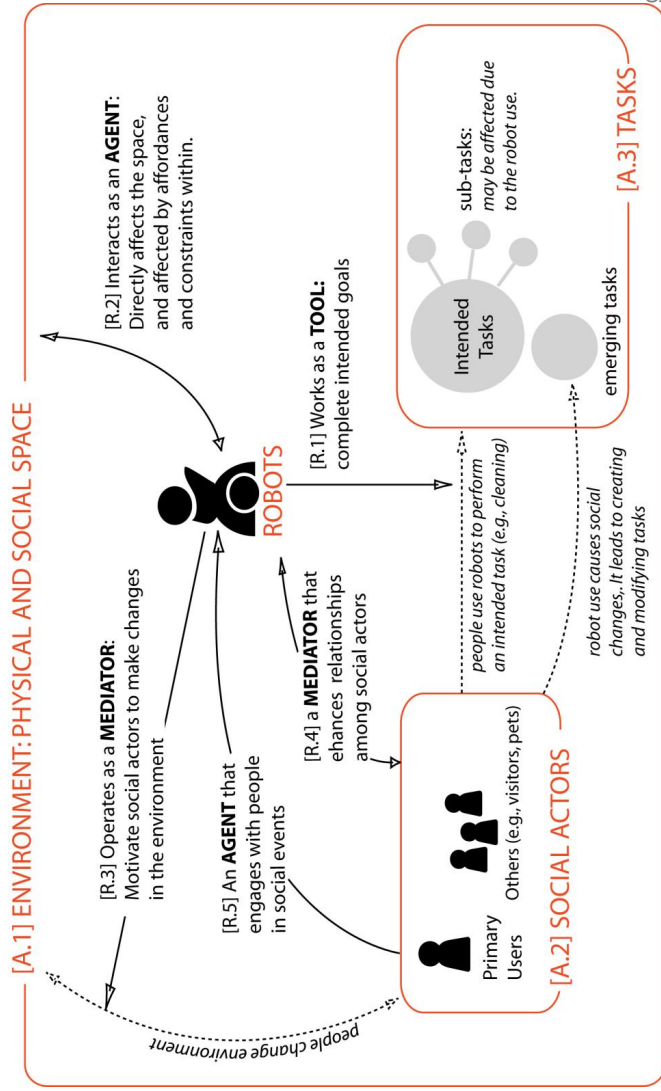


3. THEORETICAL FRAMEWORK

[Holistic and Contextual Interaction Design: project how design choices impact the overall User Experience]

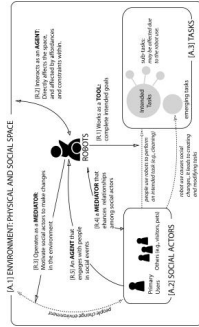
Robots are organically connected to the everyday spaces. They influence the physical settings, the social actors, and the related activities all together. Domestic Robot Ecology (DRE) is an initial framework that articulates the relationships that robots elicit with their surrounding environment. It comprises:

- **Three interaction attributes** (A.1, A.2, A.3 in the DRE figure) –the basic elements that form user experience with a domestic robot
- **Five relationships** (R.1, R.2, R.3, R.4, and R.5 in the DRE figure).



3. THEORETICAL FRAMEWORK

DRE FRAMEWORK



THREE ATTRIBUTES OF DRE

[A.1] **Physical and social space** provides a platform for interactions to occur. Physical space refers to the indoor environments, such as floors, rooms, and furniture within. Also, our studies support that the interactions occur in non-physical space such as an online social environment as people share stories, photos, and videos of their robot experiences.

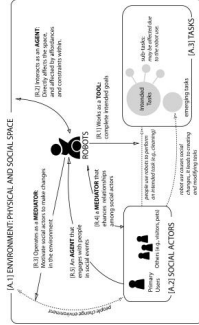
[A.2] **Social actors** are the living members in the home, such as householders, guests, and pets. Social actors can be divided into two groups: 'users' who interact with robots on a regular basis to complete a task, and 'non-users' who do not regularly use but engage in social activities with this technology.

[A.3] **Tasks** refer to the activity that the robot is designed to serve. Domestic tasks are closely inter-related and have unclear boundaries from each other, and therefore automating one task by using a robot may bring substantial changes to the connected tasks. In addition, the use of robotic products may emerge new types of domestic tasks that did not exist before prior to the robot adoption. Taking Roomba use as an example, householders created leisure activities such as creating a race track to compete with neighbor's Roomba.

Designers should begin the design process by clearly defining these three attributes for the specific robot and tasks being designed for.

3. THEORETICAL FRAMEWORK

DRE FRAMEWORK



FIVE RELATIONSHIPS

- [R.1] A tool to perform tasks: robots served as a utilitarian tool to replace the manual labor, and to improve the quality of life.
- [R.2] An agent that directly impacts the surrounding environment: robots induced physical impacts, such as removing pet hair on the floor, and moving smaller objects during the navigation.
- [R.3] A mediating factor that motivates people to make changes in the environment: robots sometimes elicit negative impacts, such as breaking a mirror and dragging wires. The limited compatibility with the existing environment mediates people to make necessary changes to incorporate robots better.
- [R.4] A mediator that enhances social relationships among household members: in our study, we found that children and men took more responsibility in cleaning after robot adoption. Further, robots often became a new means for social activities. For instance, people took robots on their vacation to showcase its performance, and they demonstrated it to the visitors.
- [R.5] An agent that engages with people in social events: people ascribe like-like qualities to a robot, and directly engage in social activities, such as giving names, genders, and personalities.

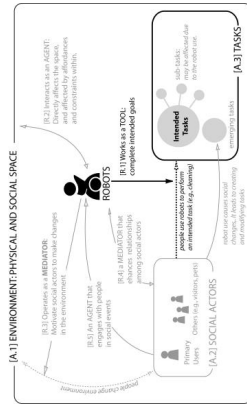
Use these relationships to create possible interaction scenarios with the robots you are designing.

3. THEORETICAL FRAMEWORK

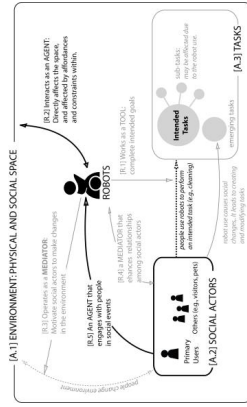
DESIGN FOR LONG-TERM ACCEPTANCE

People will love your robots at the beginning because of the novelty factor.

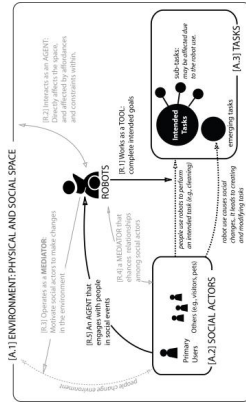
For a robot to become truly incorporated into the home, the design should support sustainability and continuous engagement. With DRE, we displays the interaction change over time in four steps to inform designers to how to focus their effort to make the experience constantly stimulating.



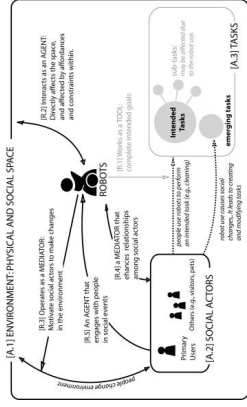
A. Pre-adoption expectation building



B. Adoption: initial impression. Draws strong emotional responses. Design for fun and expressiveness during this time.



C. Learn/Adaptation: getting into a habit of using the robot. Drastic changes appear in the environment and among household members. Show explicit sign of learning in its motion and communication.



D. Use/Retention: begin to use robot on a regular basis. Seek the value of the robot in its ability to perform the intended task more than the social and entertaining values it may elicit.



3. THEORETICAL FRAMEWORK

SUMMARY

Designing interactions for robotic products is a complex process.

In the process, designers need to understand how robots create interactions with the surrounding context. To allow the contextual understanding, this guideline offers a theoretical framework called, Domestic Robot Ecology (DRE).

DRE augment the interaction design process by:

1. helping define the attributes that play important roles in the robot interactions.
2. helping set the basic interaction scenario to complete a given task.
3. helping map the developed interactions onto DRE, and create an interaction scenario, following the relationships described. It will help reveal weakness and strength of the design in an overall user experience.

Next, we present actionable design guidelines to help construct the robot interactions.

4. ROBOT INTERACTION GUIDELINES

4.1 GENERAL INTERACTIONS: THREE DIMENSIONS

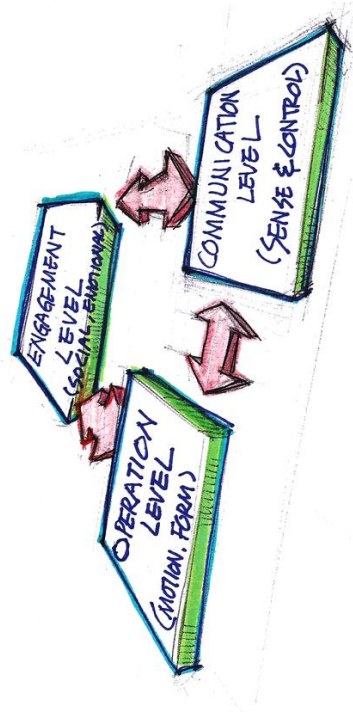
designing robot interactions requires thoughts in various levels.

First, the interactions for basic operations need be determined. They comprise how an arm moves, how it navigates around the house, how it handles a threshold, and how it looks and fits into the environment. These interactions take the longest to develop and become most influenced by technical constraints. Therefore, it should be considered first. Also, this stage involve the largest number of experts across mechanical structure, electrical/sensing technology, software development and more.

Second, the interactions for communications should be discussed. This stage determines how people should initiate dialogues to robots (e.g, button press, speech recognition, and touch). In addition to determining the mode of interactions, this stage plays an important role to detect errors and decide how a robot should act in an unexpected situation, such as being stuck on a carpet while serving a glass of water.

Third and last, the interactions should be fine-tuned to engage people with this technology. How it moves, makes gestures, speaks, and responds should be designed to socially and emotionally appeal to people.

These three dimensions are dependent to each other; they are inter-connected. For example, one cannot design how a robot approaches a person without considering the surrounding social context. This division is an attempt to add structures to a seemingly broad and ad-hoc process of designing robot interactions.



4.2. INTERACTION DESIGN: OPERATION DIMENSION

4.2.1 Plan paths for diverse proximity: global and local operations

Householders use robots for both global operations (e.g., cleaning the entire house, and delivering an object between rooms) and local operations (e.g., grabbing a remote from the floor and handing it over to a person's hand).

Robots need to adjust their movements depending on the circumstances:

- global operation: move efficiently to complete tasks and to save energy
- local operation: slower operation for fine and safe control. Expressive movements to reflect its social agency and to increase robots' perceived intelligence.



4.2.2 Change motions over time: transition from expressive to optimal

Industrial robots are designed for efficiency and optimal production. Systematic movements is critical. However, robots for the home needs different strategies.

People feel systematic and optimal movements out of the box as machine-like. They want to see the sign of a robot's learning curve. Householders prefer robots' unexpected and expressive motions at the beginning. Over time, they want robots to learn the navigating paths and act in an optimized way to serve the task efficiently.

Toward the beginning, robots need to express in its movements.

- random paths elicit entertainment and curiosity to learn more about the robots.
- People describe them non-machinery and human-like (unanticipated behaviors)
- expressive movements help establish robots' identities (leads to engagement)

Over time (in a month if used daily), robots should learn to act optimally.

- same repetitive motions remind them of machines without intelligence (lose engagement)
- less tolerance over mistakes robots make during operation (e.g., breaking glasses)



4.2. INTERACTION DESIGN: OPERATION DIMENSION

4.2.3 Design motions sensitive to orientation & height

[ORIENTATION]

Householders ascribe lifelike qualities to robots. Most commonly, people ascribe body parts that express robots' orientation such as the head and the eyes even to the Roombas that have a circular shape. For them, identifying those parts noted how they could communicate with robots.

- It is important to design to clearly represent the robot orientation.
- More importantly, robots should move with its orientation in mind. It should move forward with its face-like parts forward.
- Particularly, robots should face-forward when going into the charger. It is important if it can communicate with people while being charged. It is socially awkward to see a life-like agent facing the wall when standing.

[HEIGHT]

People can sit, stand, lay down and do more. In whichever posture they take, they will expect robots to be at their eye-level in order to exchange feedback (particularly if it takes voice commands, shows information on screen, and delivers items).

Also, for a robot that has a screen and provides info-tainment, people will try to interact with it even when it is stationed, such as being in the charger. That said, the charger and the screen cannot be on the same side; and the screen should always be facing the direction that people may approach from.



4.2. INTERACTION DESIGN: OPERATION DIMENSION

4.2.4 Balance between visual compatibility and visibility

Householders valued how it looked compatible with the rest of the household particularly when not in use (or being charged). Adjust robot's charging station until it shows visual compatibility with the rest of the house.

- Storage in visually unobtrusive yet highly trafficked area to get reminded of the use.
- Customize the external shape to appear more compatible with the house. (e.g., make it look like a fixture when not in use, and change the shape when in operation)
- Easier and more personal configuration by changing the skins to look like the floor or other parts of the house.



4.2.5 Reduce operation noise from robots, and hence allow multi-tasking from householders

Participants tend to use the robot in conjunction with other tasks in the home to save time. The operation noise from the robot often become the hurdle for the efficient use, which led to decreased use. However, a few participants use the noise as cues to identify accidents (e.g., noise stops = robot got stuck somewhere).

Again, enabling robots to communicate with householders via network such as sending a rescue email when getting stuck can minimize the need to take cues from its noise.

4.2. INTERACTION DESIGN: OPERATION DIMENSION

4.2.6 Plan for a broad range of operating environments

People will make certain changes to adopt robots such as cutting off the rug tassel. However, it will discourage them from using robots if those changes began to overwhelm their normal routines.

- List all potential hurdles that may hinder robot operation, such as thick carpets, rug tassels, bottom of lamp stand, door threshold, small toys (robot chokes and stops working), electric cords and dog pads.
- Adjusting the wheel size to overcome these items is one solution; however getting too big of wheels again creates problems including damaging expensive fine carpets, antique furniture and leaving visible tire marks on the carpet (which some householders responded negatively).





4.3. INTERACTION DESIGN: COMMUNICATION DIMENSION

4.3.1 Contextual communication: autonomy vs. manual control

In routine usage, people want robots to perform tasks autonomously via minimal to no interactions. However, In certain occasions, people want to remain in control of robots' operation. Those incidences include:

- Scheduling an operation
- Customizing or localizing the operation path (e.g, go straight from entrance to the kitchen, or staying in the living room until battery runs out)
- Programming conditional operation (e.g, only vacuum if dirt detected).

Also, they want to manually control if a robot performs any tasks that involve safety risks such as cutting vegetables or carrying heavy objects.

4.3.2 Provide an interface that tracks and logs robot activity for troubleshooting

Studies show that people will make certain changes to adopt robots such as cutting off the rug tassel. The challenge was that it was hard to identify spots that robots experience operation difficulties because robots autonomously move in spaces that do not necessarily involve human monitoring.

Participants spend weeks to make the initial adjustments by following the robot around the house, and likely to continue this practice throughout the usage. It largely decreases the product satisfaction because they feel robots demand unnecessary inconvenience and create too much load. A robot needs to log its movements and record where it met challenges as a tool for easy maintenance. That way, people can go over the data and identify where and what to adjust in the environment.

4.3. INTERACTION DESIGN: COMMUNICATION DIMENSION

4.3.3 Allow multiple modes of interaction and control

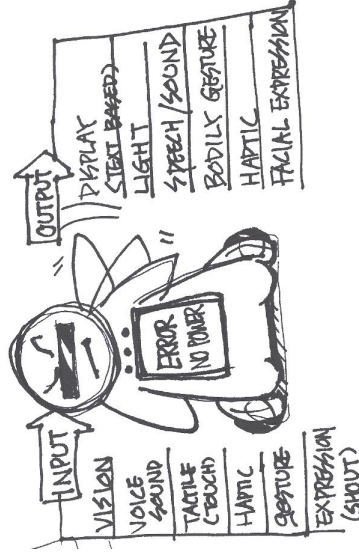
Most people selected voice commands as the default communication medium.

However because the home is large, people need to control robots that operate in distance where voice cannot reach. That said, designers should consider how to interact with robots in various proximity either using voice or other remote medium, such as an application on a smartphone or an embedded feature in a TV remote control.

Likewise, people wanted robots to communicate with them using various methods.

- Robots themselves could make visual remarks or auditory feedback to catch attention and convey messages.
- If the messages are related to maintenance, people prefer to receive in a written manner, such as showing what is required on a LCD panel.
- If robots operate in distance but need to send a message, people desire a smart messaging system, such as robot send the message to nearest TV or a monitor where the person stays or to mobile devices. That way robots can continue working on a task, and save time to take a trip to just send a short message.

In sum, people desired ubiquitous means to give and receive feedback to and from robots in the home.



4.3. INTERACTION DESIGN: COMMUNICATION DIMENSION

4.3.4 Should learn and show its learning process

Robots should be able to learn to adapt to the environment and household routines. Also, it should be able to learn different household members and recognize their preferences and needs (e.g., delivering the right type of medicine for each household member).

Further, the study shows that robots should not only learn but also should clearly demonstrate its learning process. Householders expect robots to show progressive development from being new to the environment to being familiar to the space.

They want to see the learning in the way robot acts more efficiently (e.g., completing a task quicker) and intelligently (e.g., remembering a person's name). The study shows that householders rapidly lost the credibility in robots' performance and intelligence when they see the robots make the same errors repeatedly.



4.3.5 Consider safe and secure services

Robots movements should be pet and children safe. Also, for robots that handle personal information over network (e.g., managing schedules, reading emails and connecting video-conferencing system) need to protect from getting hacked. In addition to the personal information, robots can recognize and sense a lot of household routines.

For example, robots can record your activities through embedded camera and store the information inside. The information should be safe from intrusion, and should allow customizing what robots can or cannot record. For designers it is important to draw up all possible scenarios for safety and security risks factors, and ensure that robots can provide advanced services without risking domestic lives.



4.4. INTERACTION DESIGN: ENGAGEMENT DIMENSION

4.4.1 Provide long-term engagement. Make it less predictable

Householders become bored with a robot when they could see predictable patterns and start decreasing the usage frequency which in cases led to discontinued adoption.

With Roomba, users enjoyed the random movements; they reported them expressive and unpredictable just like human-beings. They discussed that the unpredictability in robots' movements was the key for them to continue to interact with it over a period of time because it was fun and stimulating.

Also, they explained that unpredictable actions are unique to lifelike beings (not machines), which made them perceive robots as social agents and deepen the engagement. Over time, as the robot shows the same random movements, they begin to describe it boring and stupid. They wanted to see new types of movements and response patterns.

In general, people wanted robots to learn new things and become constantly stimulating to observe. However, I do not argue that all robots should begin with random and emotive behaviors. Some tasks such as health monitoring for senior people need to be carried at with precision. Also, too much randomness might confuse people as it may appear broken.

4.4. INTERACTION DESIGN: ENGAGEMENT DIMENSION

4.4.2 Create personally meaningful relationships through customizations

Householders customize robots by changing the skins or writing down names on the external case. They note the customization activities help connect them deeper with robots as not just a mass-produced artifact but something personally meaningful to them. The study shows that personal attachment positively influences people to carefully maintain the robot for long-term use.

One common way to customize robot was to give it an identity. Most notably, they named the robot, referred to it in a gendered way, ascribed personalities, and even personalized the look using stickers, skins, and knitting. It implicates that designers should consider providing means to personalize robots, such as making the external surface configurable, or enabling people to construct a robot's identity through giving it a name, a gender and a personality.

The personalization should be reversible as householders continuously negotiate on robots' identity (changing robot names) and the external surface.





4.4. INTERACTION DESIGN: ENGAGEMENT DIMENSION

4.4.3 Enhance entertainment and sociability

People are going to engage with robots in an entertaining manner whether or not the robot is designed to provide it.

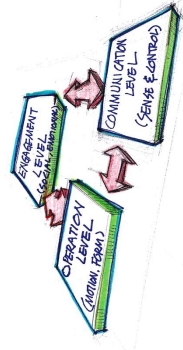
In my study, householders created a race track to compete with neighbor's robot, ran it on the pool table, delivered a gift by remotely controlling a robot and more. Through these activities they felt robots brought new social dynamics in the home, and started accepting it more as a necessary part of the household. Also, robots will be used by a various types of social actors in the home including children and pets.

Their active engagement with robots created another set of new social dynamics and hence increased the fun of using it. In particular, children played with vacuuming robots while actually cleaning the house, which they perceived as a drudgery before.

Designers could think of ways to enhance robot's entertainment by utilizing sociability, such as initiating games with children or inviting pets to play together.

4.5. SUMMARY

1. Think of robot interaction in three aspects: interaction types related to robot operation, communication, and engagement.
2. These three dimensions will help unfold the complexity in the amount of interactions to consider. Yet, these three aspects are closely connected, and thinking of one aspect can naturally impact others.



[Guiding Points for Operation Dimension]

- 4.2.1. Plan paths for both global (entire house) and local (certain areas) operations.
- 4.2.2. Change robot motions over time from being fun to being efficient in task performance.
- 4.2.3. Plan motions sensitive to height and orientations.
- 4.2.4. Balance visual compatibility and visibility .
- 4.2.5. Reduce operation noise from robots, and hence allow multi-tasking from householders.
- 4.2.6. Plan for a broad range of operating environments to allow smooth operations in all (floor) conditions.

[Guiding Points for Communication Dimension]

- 4.3.1. Allow both autonomous (let robots do tasks) and manual control (let me control robots go to the living room).
- 4.3.2. Provide an interface that tracks and logs robot activity for troubleshooting.
- 4.3.3. Modes of interaction/control: voice command most preferred. But think of controlling robots where voice cannot reach.
- 4.3.4. Learn for personalized communication (e.g., recognize personal favorites, names, gender), and show this learning process.
- 4.3.5. Consider safe and secure services to increase its utility and usefulness in everyday settings.

[Guiding Points for Engagement Dimension]

- 4.4.1. Provide long-term engagement. Make it less predictable and lifelike.
- 4.4.2. Create personally meaningful relationships through customizations.
- 4.4.3. Enhance entertainment and sociability and allow it become a companion-like being.

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VITA

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